BRITISH
POLAR YEAR EXPEDITION

FORT RAE, N.W. CANADA
1932-33

VOLUME I

DISCUSSION OF RESULTS

METEOROLOGY
TERRESTRIAL MAGNETISM AND AURORA
ATMOSPHERIC ELECTRICITY

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PLATE I

(*a*) Aerial view of Fort Rae, looking north-west.
The 1932–33 base station was on the island slightly to the left of the centre of the picture.

(*b*) The members of the expedition.
P. A. Sheppard, J. L. Kennedy, W. R. Morgans, A. Stephenson, W. A. Grinsted, J. M. Stagg.

[*Frontispiece*

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GENERAL INTRODUCTION

At a meeting of the International Meteorological Conference held in Copenhagen, September 1929, Admiral Dominik, President of the Deutsche Seewarte, Hamburg, proposed that the work so admirably organised and carried out by the International Polar Commission in 1882–83 should be repeated on a more extensive and comprehensive scale, and that 1932–33, the jubilee of the First Polar Year, would be a most suitable time for the new project. The proposal entailed the re-establishment of all the expeditionary stations occupied in 1882–83, with as many more as possible to ensure that the observational material collected would be representative alike of high and low latitudes in both hemispheres. The proposal met with unanimous approval. An International Polar Year Commission was set up to organise the programme of activities on a world-wide basis, and National Committees were convened to carry out the general recommendations in each country. The National Polar Year Committee appointed for Great Britain was composed of the following thirteen members:—

	Representative of the
Colonel Sir Henry Lyons, F.R.S. (President).	Royal Society.
Dr G. C. Simpson, C.B., F.R.S. (Secretary).	,, ,,
Professor S. Chapman, F.R.S. .	,, ,,
Professor G. I. Taylor, F.R.S. .	,, ,,
Professor R. A. Sampson, F.R.S. .	Royal Society of Edinburgh.
Dr A. Crichton Mitchell . .	,, ,, ,,
Mr J. M. Wordie . . .	,, ,, ,,
Commander L. C. Bernacchi, O.B.E.	Royal Geographical Society.
Dr G. M. B. Dobson, F.R.S. .	Royal Meteorological Society.
Mr W. M. H. Greaves . . .	Royal Astronomical Society.
Professor F. Debenham . .	Scott Polar Research Institute.
The Hydrographer *	Hydrographic Department, Admiralty.
Professor E. V. Appleton, F.R.S. .	National Committee for Scientific Radiotelegraphy.

At the time when plans were being laid, a wave of serious economic depression swept over the world, and the project for the Second International Polar Year was almost wrecked. But largely through the enthusiasm and energy of the President of the International Commission, Dr D. la Cour, Director of the Danish Meteorological Service, and by the lead given by the British Government through the Air Ministry in putting funds to the extent of £10,000 at the disposal of the British National Committee, the programme was eventually arranged. Despite the grave financial stringencies of the times, the resources of the British Committee were generously supplemented by donations of food supplies, clothing, and instrumental equipment from upwards of fifty manufacturing and wholesale firms as well as by the granting

* Vice-Admiral H. P. Douglas, C.B., C.M.G., till October 1932. Captain (now Rear-Admiral) J. A. Edgell, O.B.E., from October 1932.

of reductions in transport costs by steamship and railway lines both in England and in Canada. Details of all these are given in an appendix to the volume.

The British National Committee's contribution to the international programme has been fourfold:—

(1) By collaboration with the Meteorological Office of the Air Ministry, observations were provided from the permanent regular meteorological stations and observatories in Great Britain and also from British ships at sea. The Meteorological Office also reduced and published meteorological observations made during the year at a number of Colonial stations.

(2) By organising a scheme of special auroral observations in Scotland and the Orkney and Shetland Islands—a work largely arranged by the Royal Society of Edinburgh.

(3) By subsidising a party under Professor E. V. Appleton for making an extensive, novel, and very valuable series of observations of conditions in the ionosphere over Tromsö.

(4) By re-establishing for comprehensive meteorological, magnetic, atmospheric electrical, and auroral observations the station at Fort Rae, on the Great Slave Lake, Canada, where the joint British and Canadian Expedition under Captain Dawson, R.E.,* had had its base in 1882–83.

In the summer of 1931 the National Polar Year Committee sent Mr J. M. Stagg, who had already been provisionally chosen as the leader of the new expedition, to N.W. Canada, to find a site for the expedition as near as possible to that of 1882–83 and to make all necessary provisional arrangements with the Canadian authorities. It was found that, since Captain Dawson's occupation of the post on the peninsula of Nu-chié, the Indian Settlement had migrated farther up the north-west extension of the Great Slave Lake into Marian Lake, and that there were good reasons for the expedition making its headquarters near the new settlement. Accordingly, the 1932–33 party had its main base at the present Fort Rae (lat. 62° 49·8′ N., long. 116° 4·1′ W.), but the 1882–83 site (now known locally as the Old Fort) was occupied intermittently throughout the year as a substation for auroral photography and magnetic observations.

In February 1932 a special subcommittee of the National Committee appointed the following six members to form the personnel of the Fort Rae expedition:—

J. M. Stagg	Leader.
W. R. Morgans	Specialist scientific officers.
P. A. Sheppard	
W. A. Grinsted	
A. Stephenson	
J. L. Kennedy	Steward-mechanic.

Of these, all except Messrs Stephenson and Kennedy were members of the staff of the Meteorological Office and were seconded to the Committee by the Air Ministry for the work at Fort Rae; Mr A. Stephenson, from the Geography Department, Cambridge, had had experience of arctic work with the British Arctic Air Route Expedition to Greenland in 1930–31; and Mr Kennedy had already been employed by the National Polar Year Committee as a mechanic. All six members of the party were thoroughly examined by the Air Ministry Medical Staff before being accepted. As a safeguard against some of the contingencies which might arise on the expedition, the medical authorities of the Air Ministry provided a short but comprehensive course in first aid for two members of the party, Messrs Grinsted and Stephenson. By a further arrangement with the Air Ministry, Mr Kennedy was given a course of cooking at the R.A.F. Training School at Halton.

During March and April 1932 the provision stores for the expedition were collected at the Science Museum, South Kensington, as far as practicable in cases each of gross weight not exceeding 100 lb. to facilitate handling on the later stages

* Captain (later Colonel) Dawson died shortly after the new expedition set out for Fort Rae in 1932.

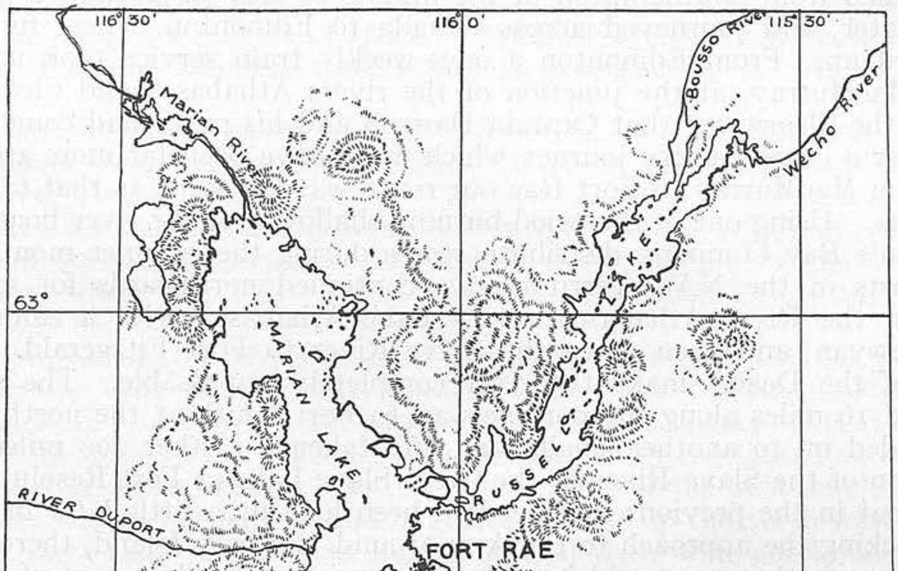
of the journey to Fort Rae. The instrumental stores were collected at Kew Observatory and packed there in specially prepared cases. When the stores were finally transported to Southampton for shipment to Montreal there were 500 cases, each of which was numbered and its contents listed to facilitate the establishment of the observatory on reaching Fort Rae.

Brief Narrative of the Expedition by the Leader

We sailed from Southampton in the middle of May 1932, landed at Montreal ten days later, and journeyed across Canada to Edmonton, where further stores were picked up. From Edmonton a once-weekly train service took us 300 miles north to MacMurray, at the junction of the rivers Athabasca and Clearwater. It was down the Clearwater that Captain Dawson and his party had come fifty years earlier, after a cross-country journey which must have been far more arduous than ours. From MacMurray to Fort Rae our route was the same as that taken by our predecessors. Using one of the wood-burning shallow-draught river boats by which the Hudson's Bay Company distribute stores during the summer months to their trading posts in the N.W. Territory, we continued northwards for another 300 miles down the River Athabasca, across Lake Athabasca, with a calling-place at Fort Chipewyan, and then down the Slave River to Fort Fitzgerald. There the "Rapids of the Dead" make the river completely impassable. The stores were transported 16 miles along the portage-way to Fort Smith at the north end of the rapids, loaded on to another small boat, and taken a further 200 miles down the continuation of the Slave River to the Great Slave Lake at Fort Resolution. Since the first boat in the previous summer had been held up a little later in the season, with ice locking the approach to the Arm around Hardisty Island, there was doubt at this stage whether we would be able to proceed on the last part of the journey at so early a date. But a spell of northerly wind had fortunately cleared the lake as well as a passage up its long northward extension unusually early, so that, with calm weather on the lake, the remainder of our journey up the North Arm, past the site of the 1882–83 station, and through the channel connecting the Great Slave Lake with Marian Lake, was almost unimpeded. (The relative positions of the stations are shown on the accompanying map, p. 4.) We reached Fort Rae on the east shore of Marian Lake on the night of June 15. All of this latter part of the journey, covering approximately 1000 miles from Edmonton, had been made very easy for us by the transport arrangements of the Hudson's Bay Company.

The North Arm of the Great Slave Lake is nearly 40 miles broad in the south and tapers off to a narrow channel leading into the Marian Lake extension. The Arm marks a geological discontinuity between the great Precambrian shield, which stretches to the Arctic Ocean in the north and to Hudson Bay in the east, and the Palæozoic limestone sediments on the south and west. The north-east shore on which Fort Rae lies is therefore completely different in character from the south shore. It is rocky throughout and for the most part sparsely wooded with spruce, jackpine, and birch trees of stunted growth interspersed with stretches of swampy muskeg. Bare, rounded, low knolls of igneous and metamorphic rock are the commonest feature right up to the lake-side; the shore is broken by innumerable small inlets, whose existence is obscured in passage up the Arm by irregularly shaped rocky islands. Apart from a fringe, perhaps less than 30 miles deep, along the shore-line, the entire stretch of continent to north and east is of uniformly low contour and is practically uninhabited. On the south side the low limestone tableland presents a wholly different prospect. The shore is much less broken, and barrier beaches of shingle are developed where the bedrock outcrops at water-level. Stretches of low tamarack, spruce, and pine lead inland from the lake to long narrow hills rising 100 to 150 feet and frequently facing the lake in low cliffs, which, with their beaches of limestone gravels, indicate changes in the level of the lake. This entire region is completely uninhabited.

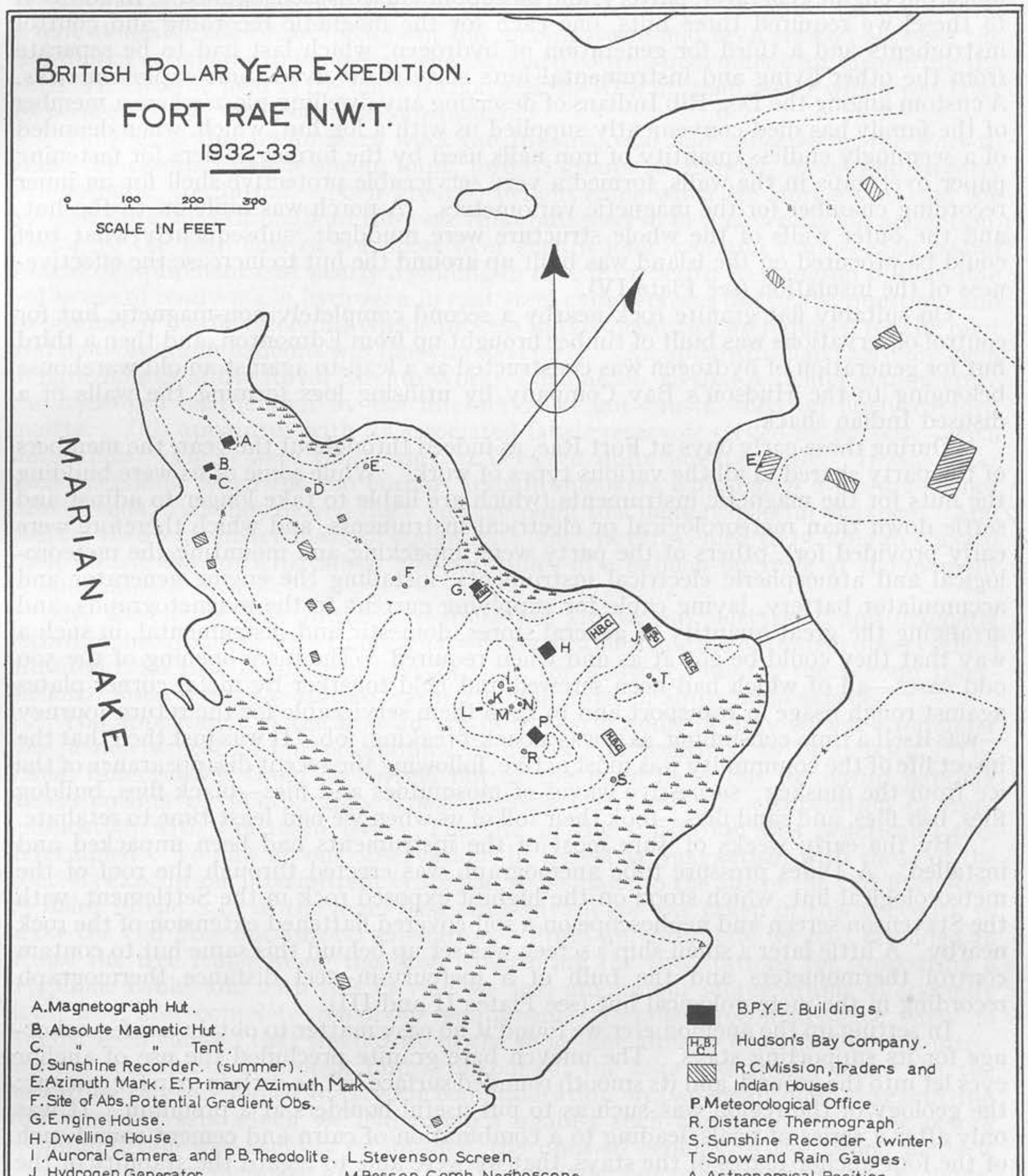
The main base of the expedition at Fort Rae was on the small rocky island which forms part of an Indian Settlement. (See accompanying plan of the Settlement.) Timber suitable for fuel is scarce in the immediate neighbourhood: ground not covered by swampy muskeg or low bush is bare granite, smoothed and scored by glaciation and interspersed with broad lava dykes and veins of quartz. The Settlement is within the Yellow Knife Reserve, and forms a meeting- and trading-place for Indians of the Dog Rib tribe. In addition to representatives of the Hudson's Bay Company and other traders, a small detachment of the Royal Canadian Mounted



North Arm of Great Slave Lake, showing positions of present and former Fort Rae sites.
(Approximate scales 10 and 100 miles to one inch.)

Police is maintained at the Fort; there is also a Roman Catholic Mission for the Indians. Behind the Settlement, on the east shore, the Indians hunt and trap along side-tracks from trails through the bush, which forms the fringe of vegetation along the shore-line: the barren lands beyond offer little protection either for human or animal life. Access into this hinterland can only be made along the bush-trails used by generations of Indians, or in summer by canoe along the innumerable narrow waterways threading inland.

On arrival, and indeed throughout our stay at Fort Rae, we benefited very greatly from co-operation with the Hudson's Bay Company, the Royal Canadian Mounted Police, and the Roman Catholic Mission. It is a privilege to record here our indebtedness to the local representatives of these bodies. In particular, by an arrangement completed in 1931 with the Hudson's Bay Company and the Royal Canadian Mounted Police, we were saved the necessity of erecting a dwelling and store-house on first landing at the Settlement. The members of the expedition were housed



Site plan of station.

partly in the police barracks and partly with the Company's factor; our stores (which, after final purchases of extra domestic and transport items in Edmonton, had increased to nearer 600 than 500 cases) in one of the Company's warehouses. We could therefore proceed with the erection of the instrumental huts. Here again the

Hudson's Bay Company was most helpful. In exchange for boarding the Company's factor and his assistant, we were allowed to convert into a meteorological observatory a shack used by the Indian traders on their winter visits to the Fort, as well as to house our engine generator, battery, and oil supplies in a disused log shed. In addition to these, we required three huts, one each for the magnetic recording and control instruments and a third for generation of hydrogen, which last had to be separate from the other living and instrumental huts since it involved some explosion risks. A custom among the Dog Rib Indians of deserting any dwelling-place where a member of the family has died conveniently supplied us with a log hut, which, when denuded of a seemingly endless quantity of iron nails used by the former owners for fastening paper over gaps in the walls, formed a very serviceable protective shell for an inner recording chamber for the magnetic variometers. A porch was built on to the hut, and the outer walls of the whole structure were mudded: subsequently what turf could be procured on the island was built up around the hut to increase the effectiveness of the insulation (see Plate IV).

On suitably flat granite rock nearby a second completely non-magnetic hut for control observations was built of timber brought up from Edmonton, and then a third hut for generation of hydrogen was constructed as a lean-to against an old warehouse belonging to the Hudson's Bay Company by utilising logs forming the walls of a disused Indian shack.

During those early days at Fort Rae, as indeed throughout the year, the members of the party shared in all the various types of work. While some of us were building the huts for the magnetic instruments (which are liable to take longer to adjust and settle down than meteorological or electrical instruments, and which therefore were early provided for), others of the party were unpacking and mounting the meteorological and atmospheric electrical instruments, installing the engine generator and accumulator battery, laying cable for supplying current to the magnetographs, and arranging the great quantity of general stores, domestic and instrumental, in such a way that they could be got at as and when required. The mere opening of the 500 odd cases—all of which had been screwed and held together by metal corner-plates against rough usage in transport and to keep them serviceable for the return journey—was itself a time-consuming, as it was a back-breaking, job. It was just then that the insect life of the community was most active, following the recent disappearance of the ice from the muskeg: successive waves of mosquitoes and flies—black flies, bulldog flies, fish flies, and sand flies—took their toll of us when we had least time to retaliate.

By the early weeks of July most of the instruments had been unpacked and installed. A Dines pressure tube anemograph was erected through the roof of the meteorological hut, which stood on the highest exposed rock in the Settlement, with the Stevenson screen and nephoscope on a soil-covered flattened extension of the rock nearby. A little later a small ship's screen was set up behind this same hut to contain control thermometers and the bulb of a mercury-in-steel distance thermograph recording in the meteorological hut (see Plates II and III).

In setting up the anemometer we found it no easy matter to obtain a safe anchorage for its supporting stays. The uneven bare granite precluded the use of anchor eyes let into the ground, and its smooth rounded surface left no certain grip for cement: the geology of the region was such as to put useful boulders at a premium. It was only after a series of trials, leading to a combination of cairn and cement round each of the four anchor plates of the stays, that we were able to regard the stability of the anemometer with any confidence; and we had learned to respect the man who can get a 45-feet tubular mast truly vertical and straight.

By July 1 Mr Morgans had already started a skeleton routine of meteorological observations and had most of the recording instruments running. Early in the same month Mr Sheppard had his Benndorf electrograph installed in the meteorological hut, with its polonium collector protruding through the wall in the S.E. corner.

Meanwhile at the other end of the island the recording and control magnetic huts had been completed, and pillars erected to carry the instruments; the three independent sets of magnetographs, a standard set of Copenhagen type, an auxiliary low sensitivity magnetograph, and a quick-run set were being installed and supplied with electric current for illumination from the storage battery and charging plant housed at a magnetically safe distance from the variometers. And by working within a tent alongside the control magnetic hut a comparison had been started between the Smith magnetometer to be used as the standard control instrument for measuring the earth's horizontal field at the main station and the Kew magnetometer which was later to be used at the Old Fort Rae substation.

During all this preliminary work the Indians, who had collected in the Fort to trade the results of their spring hunt, formed groups of amused, though apparently sympathetic, spectators. Their greatest delight came when Mr Morgans started the balloon work, and throughout the year this continued to be a never-failing attraction. Owing to the high cost of transport over such a long overland route—each pound weight of equipment cost nearly a shilling to take from South Kensington to Fort Rae—the use of ready-made hydrogen in cast steel cylinders was out of the question, and to produce it by the calcium-hydride process in the quantities we required for the pilot and meteorograph balloons was likewise too costly. An apparatus had therefore been designed for us at the Royal Airship Works, Cardington, so that we could manufacture the hydrogen on the spot by the interaction of hot caustic soda on finely divided quartz. This apparatus with its associated fabric reservoir served its purpose—with limitations. There were times when it behaved quite unexpectedly. It was after such occasions, when the too curious Indian onlookers had shared a shower of hot caustic soda, that they moved their vantage-point to a more respectful distance. And despite their customary mask of equanimity, they never seemed to be able to conceal their pleasurable anticipation at the possibility of a balloon bursting at the moment of launching.

By the end of July all the meteorological, atmospheric electrical, and magnetic recording instruments were running satisfactorily and a routine of control observations initiated. So that by midnight on July 31, the starting-time for the Second International Polar Year, the station was in running order in all its main aspects.

The appearance of the first aurora in the early hours of July 29 was a reminder that a new aspect of our programme of duties still remained to be tackled. The visual observations could be carried out at the main base, but for useful parallax measurements by photography it was necessary to establish a substation in communication with the main base. The site of the substation was practically predetermined. To link up our observations in terrestrial magnetism with those of the 1882–83 expedition, intermittent visits had to be made to the site of the Old Fort Rae, 15 miles to the S.E. of the main base, and advantage was taken of this necessity to make the Old Fort our auroral substation. From an early date we had intended to utilise the tree fringe along the shore connecting the two stations for supporting a telephone cable, and with this in view we had among our stores drums of specially light wire and complete telephone equipment. Detailed reconnaissance early in August soon showed that the nature of the shore-line already described in this introduction made such a project impracticable till the lake was frozen over. In the meantime we were forced to rely for communication on two small radio transmitting and receiving sets which we had brought against such contingencies. But before communication was usefully established, the unusual geology of the region made it necessary for Mr Sheppard and Mr Grinsted to carry out many experiments to determine the best wave-length, aerial orientation and height, and forms of earthing. After a few weeks use of radio communication between the stations we became convinced that simultaneous photography might have been continued by this means if no other had been available, but only with considerable difficulties and inconveniences, and probably much loss of effective aurora.

As soon, therefore, as the ice on the lake was thick enough for working on, we started to erect the telephone line. Parts of the lake near the main base were frozen in the first days of October, but it was not till the end of the month that the main body of the lake was sufficiently covered to allow work to begin safely. In the bush immediately behind the two stations the telephone wire was hung through porcelain insulators tied to spruce and pine trees bared of their longer branches; for the greater part of the 15-mile route down the lake, poles cut from similar trees along the lake-side were let into holes chiselled through the ice, so that as the ice speedily thickened they were frozen solidly into position. It was not practicable to lay the cable on the ice, partly because the high specific inductive capacity of the ice would have amounted to earthing the cable as it became buried in the ice by its own weight, and partly because the Indians used a winter trail which passed up the lake very near the line of the cable. Had it not been slung from poles, the cable would therefore soon have been severed by the passage of dog sleighs over it.

All of the party assisted in some stage of this work: Mr Stephenson's experience with dog sleighs was especially valuable. Since the cable was put up when the temperature was falling steadily to $-20°$ C. it was a time of general introduction to the experience of minor frost-bites.

It was also about this time that the real winter troubles with instruments began. The outdoor clocks for the meteorological instruments became erratic and sooner or later stopped. We thought we had no more to do than replace them by others supplied specifically for low temperature work, but without exception these stopped more readily than the ordinary clocks. Practically every clock on the establishment was taken asunder wheel by wheel and cleaned of all oil. At a later stage special low temperature oil itself froze within its bottle when set in the Stevenson screen. After much patient treatment, Mr Morgans came to the conclusion that the trouble lay as much in the varying pressures exerted on the axle of the balance wheel by the brass frame of each clock as in the lubrication of the spring or wheel trains.

It was soon found that the walls of the old log hut containing the Dines recording anemograph and other apparatus sensitive to low temperatures were no proof against winds of force 5–6 with temperatures below $-10°$ C. No amount of stove-stoking prevented the anemograph from starting to freeze on the first unexpected onset of such conditions. But earth scraped frozen from the hollows in the rock, boiled, and applied to the junctions between the logs forming the walls produced a "plaster" which speedily froze solid again and formed a useful protection for the remainder of the winter. As a further safeguard, the anemograph was lagged with sacking, cotton-wool, and brown paper, and finally a cupboard was built around it into which a small stove could be set if the hut temperature showed signs of going below $0°$ C.

At first, before the lake was completely frozen and absolute humidity became persistently low, rime formations on the anemometer head proved a nuisance, but this was not comparable with the subsequent difficulties in maintaining the anemograph record when the atmosphere became really dry and capillary action between the pens and the chart was brought to a standstill. A flour tin cut and shaped to fit over the drum and pen arms, and enclosing a water-bath, eased the matter, but constant watch was necessary throughout the winter till the snow and ice melted and humidity became more normal again.

Decreasing temperature radically affected the aerological work, especially the preparation of hydrogen. Water was drawn from the lake after cutting through the ice-sheet, which soon was 2–3 feet thick even in its thinnest parts; the reservoir bag for holding the hydrogen required thawing before each new supply of hydrogen could be made, for, during the generation, the action at some stage usually became so vigorous that, despite water-traps, water and caustic soda were sent into the bag along with the bubbling gas, so that, shortly after the generation had finished, the bag was frozen rigid and great lumps of ice lay in the bottom. Necessary preliminaries therefore were the warming of the ice-water, reservoir bag, and the granular NaOH and silicol, after which a blow-lamp was applied to the generator itself, otherwise the cold metal parts absorbed so much heat that the reaction would not proceed.

When the ingredients had been mixed and let into the generator, the line of action could never be forecasted. On two occasions the results were completely unexpected. On the first, Mr Stephenson was deputising for Mr Morgans, who did all this work and knew the idiosyncrasies of the apparatus thoroughly. The generator had behaved normally on three successive fillings, but on the fourth necessary to fill the reservoir bag its tactics suddenly changed. After lying dormant for a few minutes, the action started vigorously, forcing up the safety valve. In his anxiety to prevent loss of the gas, Mr Stephenson pressed on the valve in the hope that matters would soon quieten, but the valve suddenly blew up with Mr Stephenson's hand on it, and a fair proportion of the contents of the generator—a hot mixture of NaOH and Si—were showered over him. Later in the year Mr Morgans had a narrower escape. On this occasion the generator simply exploded. The reservoir bag was ripped into ribbons and the bottom was blown clean off the water-trap, the windows of the shack were sent out and the roof was raised bodily from the log walls. It was an anxious moment for all, till Mr Morgans came out scatheless from among the debris.

The preparation of hydrogen was not the major difficulty in carrying out our programme of aerological observations. Much greater, because beyond our control, was the recovery of the meteorographs after the ascents had been successfully made.

After careful consideration and consultation before leaving England, we were convinced that in our short time at Fort Rae we could not hope to make any significant contributions to the existing body of knowledge of the thermal structure of the first few kilometres of the atmosphere over subarctic regions. But we were assured that any information we might obtain about the tropopause and lower levels of the stratosphere over that part of Canada would be of value. Throughout our meteorological work, therefore, we aimed at the stratosphere or nothing, though perhaps it should be stated here that later experience made it seem doubtful whether we would have recovered many more of our meteorographs even if we had contented ourselves with humbler heights.

At an earlier stage in this introduction enough has been said of the difficult nature and almost uninhabited condition of the country around Fort Rae to indicate that we could not expect either to hunt for the meteorographs ourselves or to be optimistic about their being accidentally found by Indians. Quite early in the autumn of 1932 an aeroplane with brilliantly coloured wings and fuselage disappeared while flying a known course from Fort Rae. A search by ten or more aeroplanes was continued for more than a week before the machine was discovered in the bush only a few miles from our station. This made it clear to us that even if a meteorograph ultimately fell within a very short distance of Fort Rae it would be no easier to discover than if it had been 200 miles away.

Various methods were used to increase our chances of recovery. In order that each balloon might attain tropopause height as speedily as possible and so reduce the time during which it was being carried away from the station, it was filled to its maximum safe capacity. A brilliantly coloured ribbon, $\frac{1}{4}$ to $\frac{1}{2}$ mile long, was attached to each meteorograph to increase the chances of its presence being made known to Indians on their trapping trails; and by courtesy and co-operation of the Department of Indian Affairs, the Roman Catholic Mission, and the traders, all the Indians who used Fort Rae as settlement were informed of the significance of seeing such a ribbon in the bush, and a reward was offered for bringing in the meteorograph. In addition to these aids, each meteorograph ascent was preceded by one or more pilot balloon ascents to ascertain the suitability of the upper currents for carrying the meteorograph over those regions where we thought the chances of recovery might be greatest. But preliminary analysis of the upper atmospheric circulation over Fort Rae soon showed that even from the highest pilot balloon ascents (which naturally attained heights lower than those we were aiming at) our information about the possible ultimate destination of the meteorographs could easily be 180° awry. A balloon disappearing to the N.W. could be brought back nearly overhead and ultimately fall to the S.E. of our station.

Two out of twenty-eight meteorographs were recovered, both by Indians while hunting 100 miles or more to the north and east of Fort Rae. Both records were representative of mid-winter conditions and have given information of conditions well into the lower levels of the stratosphere.

The winter regime demanded from Mr Grinsted careful treatment of the engine generator and accumulator battery, which supplied current for the magnetographs and other instruments. The dilapidated shack in which the battery was installed behaved even more like a Stevenson screen than the meteorological hut: it was impracticable to improve it far enough to warrant introducing wood stoves for general heating. Hence Mr Grinsted drained the oil out of the engine each time after charging, so that it could be heated again before use. But more than once this proved insufficient to get the engine started. The oil became so viscous that it could not be drawn off for a fresh warming, with the consequence that the engine and generator had to be dismantled and heated *en masse* on a stove to make the oil run off. After a few such experiences Mr Grinsted made a box to fit over the engine, so that the whole casing could be warmed preparatory to each running before the oil was introduced.

The accumulators showed a surprising sensitiveness to cold. So long as the specific gravity of the acid was 1·200 or above, the accumulator could be allowed to cool to $-35°$ C. without freezing; but if the accumulator was partly discharged so that the gravity of the acid was below 1·200 there was constant risk of freezing at almost any temperature below 0° C. This entailed more frequent charging of all the small accumulators used in the various pieces of Mr Sheppard's atmospheric electrical apparatus and the other jobs for which they were in constant use, as well as maintaining the storage battery at as little below 0° C. as possible. For the latter purpose Mr Grinsted housed the whole battery in an incubator box lined with asbestos, and night lights were burnt inside it constantly during the winter.

Mr Sheppard too met unexpected difficulties with the electrical and magnetic apparatus. Frictional charges appeared on the Benndorf electrograph even in the slow motion of the recording paper over the metal rollers: rocky ground, dry snow, and the dry log huts resting on the rock made the maintenance of a good earth a troublesome matter. Of the control magnetic instruments the earth inductor required most attention. To keep the standard Weston cell (used in the potentiometer of the Smith magnetometer) above 0° C. it was necessary to have a small wood-burning stove of copper in the control hut. Since such wood stoves generally burn either fiercely or not at all, steep temperature gradients were frequently set up within the hut, with the result that thermo-electric currents were generated in the galvanometer circuit of the inductor. Mr Sheppard largely eliminated these by building a mica-windowed case for the galvanometer, and by lagging it heavily with cotton-wool. As far as possible, too, the copper-wire leads from galvanometer to inductor were replaced by brass.

Though the telephone system connecting the main base and substation, with extensions at each end to the auroral shelters, turned out to be indispensable, it required frequent attention. To keep the wire well above the ice so that Indians travelling by night would not be injured, and at the same time to minimise the number of poles let into the ice for support, the cable had been bound under considerable tension to the insulators tied to the poles. Wind on the open stretches of the lake and the effect of low temperature made the insulators friable and led to occasional breakages of the cable at awkward points between the stations. Again, since we had not employed a second wire but depended on an earth return, earth pins were driven through the ice to make contact with the yet unfrozen water. But as the ice thickened from 3 feet to 5 or 6 feet the original pins became more and more embedded, so reducing the efficiency of the return circuit. New ice-holes had to be cut over deeper parts of the channel in the lake, and steel rods 4 feet long, with trailing wire attached, were let down into the water. To these rods the earth wire was attached. In this way fairly good communication was maintained throughout the auroral work, except on the isolated occasions when "husky" dogs were not content with chewing the rubber insulation from the extension wires, but severed the wire as well. A similar display of misguided taste on the part of rodents in the early autumn lost us a batch of photographs. While the plates were drying after development, the emulsion was almost completely gnawed off.

Either to carry out magnetic observations near the 1882–83 site or to take charge of the auroral camera there, all members of the party shared spells of duty at Old Fort Rae sometime during the year. Since trees suitable for building logs were even more scarce there than around the main base, we did not wish to build another hut, but found that an old one already existed near the site. It was owned, but only occasionally occupied, by a very old half-breed Indian and his squaw, who had helped—and clearly remembered—Captain Dawson in 1882–83. But neither this link with our predecessors nor the offer of presents of tobacco was sufficient to induce these two to reckon the rent in any other terms than its trading value in good silver-fox pelts, which, to pounds and shillings people like ourselves, seemed rather high. But there was no alternative.

In the winter months the journeys and transport of food-stuffs up and down the lake between the two stations were made by dog sleigh, Mr Stephenson presiding over all the arrangements. Before the freeze-up in 1932 and after the thaw in 1933 the expedition's canoe, *Aurora*, was used for the journey, as well as for visiting the nets hung vertically across the lake to catch questionable fish mainly used for dog food. Both at the time of occupation in 1932 and on evacuation in 1933 we were indebted to the Royal Canadian Mounted Police for assistance in transporting from the main base the great proportion of our stores required at the substation.

Throughout the year the time schedule of our duties was necessarily elastic, but the general plan was dictated by the following main aspects of our programme:—

(1) Full meteorological observations every three hours.
(2) Observations of cloud every hour in most months.
(3) Observations of aurora at least every five minutes when no photography was in progress (*i.e.* when the substation was not occupied) and continuously during photography.

The daily routine of atmospheric electrical and magnetic observations as well as the aerological work was covered by the duties required for these three main aspects. Broadly, the duties which formed the basis of routine throughout the year were as follows:—

(*a*) *Early Duty*.—One man from 6 a.m. till 6 p.m., but if aurora was active the member on this duty was called earlier (usually 4.30 a.m.) to join up with the late duty man.

(*b*) *Normal Duty*.—Two men from 9 a.m. till midnight, responsible for the maintenance of the general work of the observatory during daylight hours and aurora till midnight.

(*c*) *Late Duty*.—One man from noon till 6 p.m. and then from midnight till 4 a.m. or to join up with the early duty man.

(*d*) *Old Fort Duty*.—One man at the substation for auroral photography or magnetic observations.

(*e*) *Domestic*.—Cooking and at times taking part in early morning meteorological observations. This last duty was Mr Kennedy's invaluable contribution to the expedition's work, but he was relieved at times by Mr Stephenson. The other duties were shared among the remaining members of the party.

Through the generosity of a large number of wholesale and distributive firms we had with us a good assortment of food-stuffs. In the main these kept in good condition throughout the year. We had one early and serious disappointment.

Among the presents of commissariat was one consisting of about half a ton of tinned meats, which, we were assured, included an assortment of ready-made dishes. Either because the meat arrived at South Kensington so well packed or because we disliked looking into the matter too closely since it was a gift, we shipped the consignment without examination. Our chagrin was patent and enduring when, as the cases were opened one by one, they were each of them found to contain bully beef. Luckily, when the Indians were about the Settlement at intervals throughout the year, we were able to supplement these products of Argentina with variants of fresh meat in the form of moose, caribou, and, less frequently, bear.

Apart from the incidents already described in connection with the hydrogen generator, none of us had any serious accidents or illnesses throughout the whole period, though a serious catastrophe was just avoided by prompt action on the part of Messrs Morgans, Sheppard, and Kennedy. The dwelling-house caught fire on November 5. It was an old log hut, tinder-dry; and the lake was frozen. Fortunately, Mr Sheppard was working outside and first noticed large flames bursting up through the roof; his early alarm saved the building and its contents. Within a few minutes all the inhabitants of the Settlement had formed bucket chains from ice-holes in the lake, while on the roof or inside the hut the burning wood was being hacked away to prevent spreading. Only after part of the roof had been destroyed was the fire got under control, and the hut, with our personal belongings, saved. Within a few months after our departure the same hut was completely demolished in another fire; one of the occupants, a corporal in the Royal Canadian Corps of Signals, was burned to death, and some instruments which we had transferred to the Canadian Meteorological Service were destroyed.

We continued the complete programme of observations till midnight August 31, 1933, and some of the recording instruments were kept in operation into the first few days of September, after which everything was dismantled and packed. By the second week of September most of the instruments and that part of the equipment which we had decided to re-ship to England were once more in their cases; the remainder was disposed of at what prices we could get from the inhabitants of the Settlement. Fifteen months to a day after arriving at Fort Rae five of the party left by plane for Edmonton, the leader leaving a fortnight later after seeing the equipment started on its return to England by the slower lake and river transport by which it had come.

Contrary to expectation, we had had fairly frequent communication with Edmonton and England during our stay at the Fort. Two winters before our arrival a reputedly rich discovery of gold and pitch-blend ores on the south-east shore of the Great Bear Lake to the north of our station led to a rush of prospectors and miners, and this rush continued during 1932–33. So that whereas up to 1931 Fort Rae had been one of the most isolated trading posts of the Hudson's Bay Company, it suddenly developed into a fuelling station for aeroplanes passing from the south to the mining camp. By the time we left there was a fairly regular mail service during those periods of the year when planes could use either skis or floats.

Apart from the main body of the Great Slave Lake itself, 100 miles southward of Fort Rae, the nearest moderating influence on the climate of the region is the Arctic Ocean 300 miles to the north and, since this is landlocked in the Canadian Arctic Archipelago, it is frozen for many months of the year. The climate of that part of Canada is therefore quite continental, though we were told that Föhn winds blowing from the North Pacific Ocean over the Rocky Mountains in the west sometimes produce rapid and startling rises in temperature during mid-winter. A few such rapid changes occurred during 1932–33, but except on two or three occasions they were never large enough to raise the temperature above $-10°$ C. between early November and the last weeks of April. A feature of the conditions in such a region seems to be the regularity with which the more obvious natural phenomena recur at the same time to within a fortnight from year to year. After a short summer in August and autumn in September, temperature begins to fall rapidly in early October, when the first snow is due. From then till the end of April temperature is steadily below freezing-point, for many successive days even below $-25°$ C. The ground is frozen and snow-covered, though the total snowfall is probably seldom more than 2–3 feet, and for the greater part of the time the lake is bound with a 4–6 feet covering of ice. Towards the end of April the snow begins to disappear, and moccasin footwear must be protected by rubber overshoes. By the end of May the snow has gone and the ice on the lake is gradually giving way. Dog-sleigh transport is replaced by canoe round the edges of the lake. During July the ice completely disappears; then a short warm summer can be expected, when temperatures can be as high as in England and when tree, bird, and insect life—especially the latter—make up in growth and vitality what they lack in duration of life. A few weeks of autumn transition in early September, when ducks and geese fly southward from the Arctic, when trees quickly wither, and then the cycle is repeated with the start of freezing of the lake on the first clear night.

It would be a very pleasant duty to close this introduction with acknowledgments of all the help and advice so generously given at every stage of the expedition's activities. But to do this adequately would require more than the space allowed us. We wish, however, to record our appreciation of the disinterested kindness of those firms enumerated in Appendix I who presented us with contributions to our stores or granted us reduction in fare and transport charges. To the Air Ministry and to other Government departments and scientific institutions referred to in Appendix II we acknowledge our indebtedness for loans, which formed the greater part of our instrumental equipment.

We would thank the Hudson's Bay Company, the Royal Canadian Mounted Police, and the officers of the Department of Indian Affairs and the Department for the North-West Territories, both in Ottawa and elsewhere in Canada, for their great interest, help, and advice. We are also indebted to Mr Patterson and his staff of the Canadian Meteorological Service for friendly consultations and guidance.

Special acknowledgments are due to Dr (now Sir George) Simpson, the Secretary of the National Polar Year Committee. From his wide experience of similar high latitude work he gave very practical guidance and personal advice, which were completely indispensable in all the arrangements for the expedition and in the subsequent work of preparing this and other publications. As Director of the Meteorological Office, he granted every facility afforded by the resources of the Office for purchase and loan of instruments, as well as for consulting members of his staff about the varied problems which arose during our preparations. In this latter connection we were particularly grateful for the invaluable assistance given by Messrs J. S. and L. H. G. Dines of the Meteorological Office, and their respective staffs of the Instruments Division, South Kensington, and the workshop at Kew Observatory. We would also record our appreciation of the assistance generously given by the staff of the General Services Division of the Meteorological Office, Kingsway, of which Division we would particularly mention Miss D. G. Chambers, who, in her capacity as Assistant Secretary of the National Polar Year Committee, took a heavy share of the clerical work before and after the expedition.

For the very varied and extensive programme of duties to be carried out in unusual circumstances the party to Fort Rae was small. Except on the few occasions in the spring and summer months when Mr Kennedy could be temporarily relieved from his domestic duties—mainly by Mr Stephenson—he bore the monotony of the cooking alone; the remaining members of the party shared equally the routine of meteorological observations, auroral observing, and auroral photography. Without any rigid definition of boundaries, Mr Morgans was in charge of the heavy programme of meteorological and aerological work, Mr Sheppard of the observations in atmospheric electricity, Mr Grinsted of the magnetographs, and Mr Stephenson of surveying, observing with the Kew magnetometer, and the general domestic arrangements at, and transport between, the main and sub-stations. Messrs Sheppard and Grinsted between them looked after all such technical matters as the wireless and land-line telephony, the care of the engine generator and battery, the timing arrangements, and the control magnetic observations at the main base. At the substation the comparison magnetic observations were shared by Messrs Morgans, Sheppard, and Stephenson.

It is not for any of us who were thus intimately concerned with the work done at Fort Rae to judge of its success; this must be left to those into whose hands may come the results of the expedition, as presented in later sections of this and other publications. Whatever merit the results may have is to be attributed to the sustained enthusiasm of every member of the party, and to the care and patience given by each, not only to the special duties which fell to him, but to the common routine of the work at Fort Rae.

METEOROLOGICAL OFFICE,
EDINBURGH,
December 1935.

DESCRIPTION OF THE PRESENT VOLUME

This volume contains the discussion of the data from the four main subdivisions of our programme of work at Fort Rae. It includes only those tables of hourly values, etc. which are specifically required for following the discussion; the basic tables formed directly from the observational material are collected in Volume II. In the present volume Mr Morgans has discussed the meteorological results, Mr Sheppard those in atmospheric electricity, and Mr Stagg the magnetic and visual auroral observations (together in one section). In presenting these last we have had to be content to give some of the more straightforward statistical aspects of the great body of detailed auroral notes, together with an account of some of the main characteristics of auroral phenomena as deduced from these notes. Further use will be made of the observations in investigating such questions as the correlation of auroral and magnetic phenomena, but it has been considered inadvisable to delay publication of the main results here presented till these and other investigations, which will be carried out in meteorology as well as magnetism and aurora, are ready. For a similar reason the publication of results accruing from the measurements of the auroral photography is also deferred to a later volume.

It remains to be added that accounts of a few investigations, utilising particular aspects of the Fort Rae results and undertaken during the reduction of the data presented in this volume, have already been published separately by Mr Stagg. They are:

(1) "The Diurnal Variation of Magnetic Disturbance in High Latitudes," London, *Proc. Roy. Soc.*, A, **149**, pp. 298–311 (1935).

(2) "Numerical Character Figures of Magnetic Disturbance in Relation to Geomagnetic Latitude," *Terr. Mag.*, **40**, pp. 255–262 (1935).

(3) "Aspects of the Current System Producing Magnetic Disturbance," London, *Proc. Roy. Soc.*, A, **152**, pp. 277–298 (1935).

(4) "Some General Characteristics of Aurora at Fort Rae, 1932–33," London, *British National Polar Year Committee*, pp. 1–6 (1935).

The contents of these papers are not reproduced in this volume, but references are made to them where necessary. Since the account of the characteristics of aurora, which forms the subject of the fourth paper, was intended only to summarise some of the more important general features of aurora at Fort Rae, no details were given. A brief synopsis of the characteristics described in the paper has, therefore, been given in § 113 of the discussion of the magnetic and auroral material, and the more prominent of the characteristics exemplified.

Copies of any of the above-mentioned papers may be obtained by application to the Bureau of the International Polar Year Commission, Copenhagen.

METEOROLOGY

By W. R. Morgans, M.Sc.

INTRODUCTION

During the year 1882–83 Great Britain collaborated with Canada in establishing a station at Fort Rae, a trading post on the North Arm of the Great Slave Lake. The station formed one of a series of circumpolar stations occupied, in accordance with a prearranged scheme, for concerted physical observations extending from 1882 September 1 to 1883 August 31. The meteorological results of the expedition to Fort Rae during this First International Polar Year have been published under the title, *Observations of the International Polar Expeditions, 1882–83, Fort Rae,* but the results obtained have never been discussed.

Furthermore, if reference be made to the original volume of published results, the reader will find practically no information as to how the hourly values have been determined. There is very scant information indeed, so that the reader is at a loss to find out what corrections were applied to the barometer readings, what methods were exactly used to determine the hourly values of wind velocity, to what instruments do the hourly values of humidity refer, etc. But as the results for this first expedition have been discussed wherever suitable in this work, it would be advisable to reproduce here all the information which the original volume contains relative to the meteorological station.

The meteorological equipment consisted of 2 Kew pattern (marine) barometers, 2 aneroid barometers, 2 cup and dial anemometers (small size), 1 rain-gauge, a number of mercury and spirit thermometers, 2 hair hygrometers, and a zinc thermometer screen.

Captain Dawson, the leader, then states that, "Only one observer being as a rule available for magnetic and meteorological observations, the meteorological instruments were placed, as shown in annexed plan (page 18), near to the magnetic observatory. They were read at each hour in the following order: Barometer, anemometer, dry and wet bulb thermometer, hair hygrometer, wind, clouds, weather, and aurora. The self-registering thermometers were read at 9 a.m. every morning, and at the same hour the amount of rain or snow in the rain-gauge was recorded, and on alternate days the readings of the earth thermometers. The solar radiation thermometer was read at the first hour after sunset.

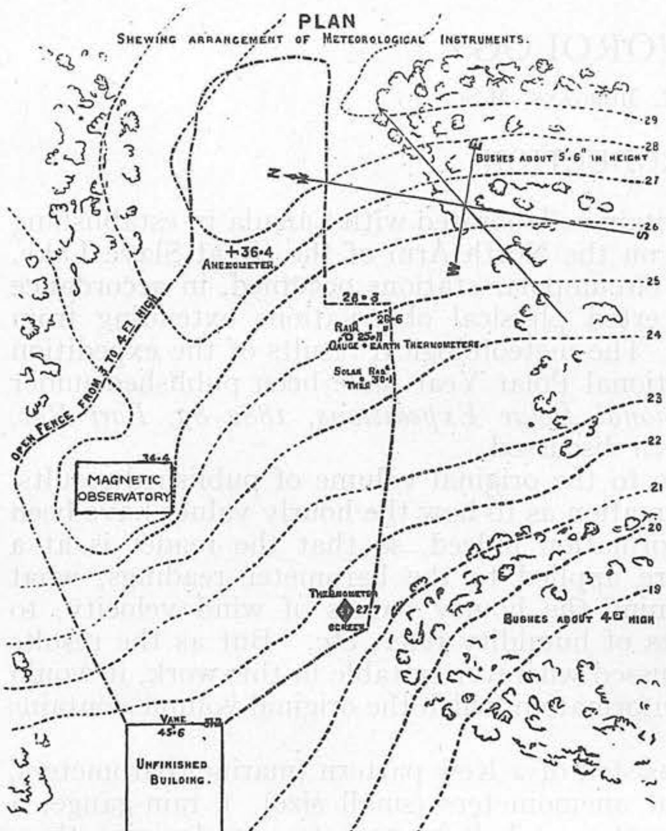
"The barometer, . . ., was placed in the observatory with its cistern 18 feet above the level of the lake. It was hung in a good light and screened from the sun and from the fire. It appeared to be in good order, and its performance was quite satisfactory, as far as could be judged by comparison with the aneroid. The instrument was not brought back to England for re-verification on account of the great probability of damage on the journey home, and had it been found to be out of order on receipt, there would have been no possibility of determining whether the injury had been received before or after leaving Fort Rae. It has already been explained that one barometer was broken on the way out.

"The dry and wet bulb mercurial and spirit thermometers were placed in a zinc screen, of Professor Wild's pattern, with their bulbs 5 feet 10 inches (1·77 m.)

above the ground. During the winter this height was reduced by 8 or 9 inches, owing to the accumulation of snow. The maximum and minimum thermometers and a hair hygrometer were placed in the same screen. In February a wooden roof was added to protect the screen from the rays of the sun.

"The rim of the rain-gauge was kept at a height of 1 foot (·32 m.) above the surface of the ground or of the snow. . . .

"The position of the observatory rendered it difficult to find a good position for the anemometer, on account of the hill to the north-east. Winds from this quarter were, however, rare, and the anemometer was well exposed to the prevalent winds, which were north-westerly or south-easterly. The estimated force by Beaufort's scale has been used in the reductions, a comparison having shown a close agreement with the anemometer readings. An anemometer was placed on an island in the lake, but it was so frequently stopped by snow drifting into the works that no use has been made of its readings."



Plan of Old Fort Rae, 1882–83.

The above paragraphs contain all the information relating to the meteorological station given in the published results of the first expedition. No information is given upon the numerous questions that arise in the reduction of the data, so that the reader has to accept the hourly values published for that year.

Since the First International Polar Year, the site of the trading post at Fort Rae had been moved 25 km. farther north into the Marian Lake extension of the North Arm, and it was at the new Rae that the meteorological observations were taken during the Second International Polar Year, 1932–33. In order to avoid confusion and repetition between the two Fort Raes, the old site will be referred to in the discussion as Old Fort Rae, whereas the new site will be called Fort Rae.

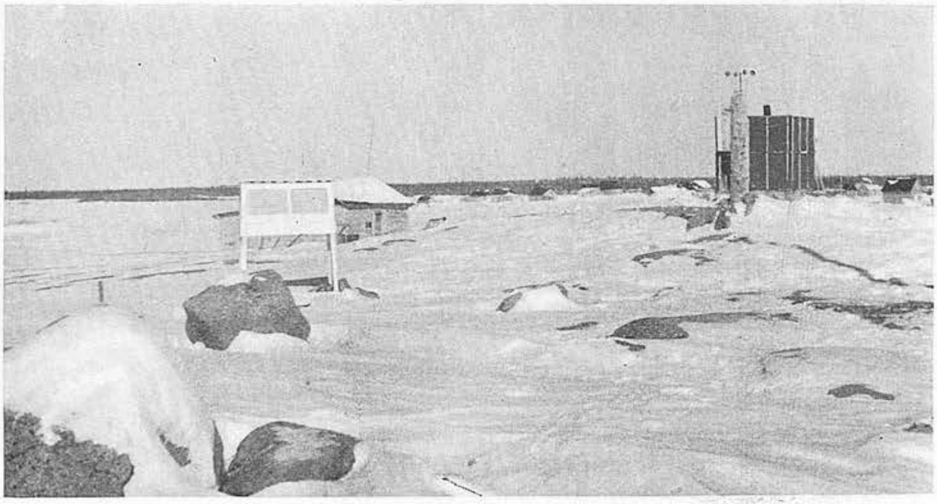
The site at Fort Rae, with an excellent exposure from all directions, was admirably suited for establishing a meteorological station. The meteorological equipment was very complete, practically all instruments being run in duplicate to avoid loss of record occasioned by the stoppage of clocks. A general description of the meteorological work and some of the difficulties has already been given by Mr J. M. Stagg.* The distribution of the various meteorological instruments can also be seen by reference to the plan of the Settlement in the General Introduction to this volume, showing the complete lay-out of the observing station.

Plate II (*a*) shows the free exposure of the Dines anemometer, with the subsidiary pressure plate anemometer at the end of the roof gable.

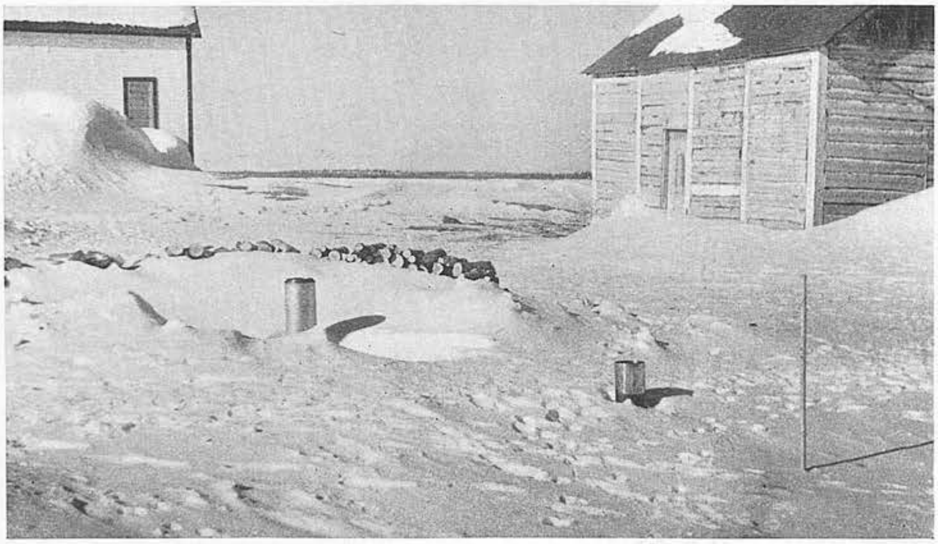
Plate II (*b*) shows the site of the large Stevenson screen looking north-east. The

* J. M. Stagg, "British Polar Year Expedition to Fort Rae, N.W. Canada, 1932–33," *Quart. J. R. Met. Soc.*, vol. lx. See also General Introduction to this volume.

(*a*) Meteorological hut showing Dines pressure-tube anemometer and auxiliary wind indicator.



(*b*) The Stevenson screen, cup anemometer, and auroral shelter.



(*c*) The Hellmann-Fuess recording snow-gauge, the check-gauge, and the snow-pole. The snow-gauge is partially submerged after heavy drift.

[*To face p.* 19

site was well exposed from all directions, and the highest ground lies to the east of the screen at the site of the auroral enclosure.

Plate II (*c*) shows the sites at which precipitation was measured both in the summer and the winter. The ring of partly used cord wood shelters the Hellmann-Fuess snow-gauge from the north-east winds blowing between the buildings. The check gauge remained at the same position throughout the year.

During the discussion of the meteorological observations taken at Fort Rae it was thought advisable, in order to make the results more complete, to incorporate, as far as possible, all the results made at Old Fort Rae. Consequently the meteorological data which are discussed comprise the observations during at least a period of 24 months for all the elements. Much work, such as diurnal inequalities, harmonic analysis, resultant winds, etc., remained to be done on the results of the Old Fort Rae data before they could be used in the discussion, and for the sake of completeness such results have been incorporated in the discussion or the tables wherever suitable.

The following discussion would not have been possible, however, were it not for the help I have received from other sources. I wish to express my thanks in particular to Messrs J. M. Stagg, P. A. Sheppard, W. A. Grinsted, and A. Stephenson, members of the expedition, who took full part in the meteorological work throughout the year and who gave valuable aid in tabulating the records of the meteorological elements; to Mr Kennedy, who afforded relief to the members of the party by taking occasional early morning observations. I am very grateful to Mr L. H. G. Dines, who gave me valuable information and advice on calibrating and preparing Dines meteorographs for ascent, and who made the work much easier at Fort Rae by the excellent manner in which all the component parts for the aerological work had been assembled. My thanks are also due to Mr Nichol and to the assistants at Edinburgh, who all helped with much of the computing work after our return to England; to Messrs H. E. Forster and A. Lee, who have prepared the diagrams under my supervision at Catterick.

In conclusion, I wish to express my thanks to the British Polar Year Committee for giving me the opportunity of being a member of the expedition and for the privilege of undertaking the discussion.

PART I.—TEMPERATURE

I. INSTRUMENTS, EXPOSURES, AND METHODS

(a) *The meteorological screen*.—The meteorological screen used at Fort Rae was the large double-louvred Stevenson screen of the standard pattern as used at most of the British meteorological stations. The site selected was close to the highest point of the small Hudson's Bay Island on which the station was established, so that the screen had a free exposure from all directions. The base of the screen was 104 cm. above the surface of the grass during the summer, but during the winter a little snow accumulated at the base to a depth of about 15 cm.

The ventilation throughout the year was entirely satisfactory, so that the thermometers registered practically free air temperatures. Occasionally snow drifted into the screen, but the amount was usually slight and it could easily be brushed away. The snow accumulation within the screen rarely put the thermograph or the hair hygrograph out of action.

Within the screen were placed wet and dry bulb thermometers, a maximum and minimum thermometer, a weekly thermograph, and a weekly hair hygrograph, all of the standard pattern as used in the British Meteorological Office.

(b) *The ship's screen*.—For the purpose of ventilating the bulb of the distance recording thermograph, a small ship's screen with double louvres was erected on the south-west side of the main station at a distance of 14 feet away from the wall. The Bourdon tube was led out from the thermograph through a hole in the south-west wall. It was then bent downwards to the earth, and was led below the earth to a point underneath the ship's screen. Coming vertically upwards, the bulb entered the screen through a hole in the under surface, and it was rigidly fixed by two copper bands to a stay within the screen. In the screen and alongside the bulb was suspended a thermometer, which was read at four of the standard hours of observation.

The exposure of the ship's screen was not so good as that of the Stevenson screen. The main station itself shaded it from north-easterly winds, and the higher ground to the north sheltered it slightly from winds from that direction. The possible sites for the ship's screen were limited by the length of the Bourdon tube.

The ventilation of the screen, however, throughout the year was quite satisfactory.

The temperatures shown by the thermometer suspended in the ship's screen agreed on the whole satisfactorily with those shown by the dry bulb thermometer in the Stevenson screen, but there were occasions when they differed by amounts as great as 2° C. A comparison between the temperatures shown by the thermometers in the two screens for the hours 2h, 8h, 14h, and 20h Z.M.T., for months equally distributed throughout the year, gives the following table of mean differences.

TABLE I.—MEAN MONTHLY TEMPERATURE DIFFERENCES (STEVENSON SCREEN – SHIP'S SCREEN) BASED ON OBSERVATIONS AT 2H, 8H, 14H, AND 20H Z.M.T.

Month .	Aug./32.	Nov./32.	Feb./33.	May/33.	Aug./33.
	°C.	°C.	°C.	°C.	°C.
Difference .	−0·14	+0·05	0·00	+0·02	−0·01

The table shows that, for four out of the five equally distributed months selected, the mean monthly difference between the readings of the thermometers in the two screens was exceedingly small and lies well within the personal error of reading a thermometer. For the month of August 1932 the thermometer in the Stevenson screen read on the average 0·14° C. below the thermometer in the ship's screen.

(c) *Thermographs.*—Two thermographs were used during the year, one a weekly bimetallic thermograph of the standard type, as used by the British Meteorological Office, and fully described in the *Observer's Handbook* issued by that office; the other consisted of a single pen distant reading thermograph, as made by Negretti and Zambra.

The bimetallic thermograph was placed in the Stevenson screen, and throughout the year the records obtained from this thermograph have been taken as the standard. Some difficulty was experienced in keeping the clock running during very low temperatures, but the most satisfactory method found at Fort Rae was that of cleaning the clock of all oil and lubricating with graphite.

The ordinary clock of the Meteorological Office functioned satisfactorily without attention during days of a mean temperature of −10° C., but below this temperature the clock had to be cleaned of oil and lubricated with graphite. The clocks would then function satisfactorily during days with a mean temperature as low as −20° C., but for lower temperatures a careful adjustment of the balance-wheel system had to be made. Practically all stoppages of the clock during the winter occurred during rapid changes of temperature from very low values to comparatively high values for the season and *vice versa*.

The thermograph was, on the whole, a satisfactory instrument with which to work. The bimetallic control was strong, and the sensitiveness of the instrument was very uniform over the whole scale. The scale value remained uniform except during

TABLE 2.—PARTICULARS OF THERMOMETERS IN USE AT FORT RAE, 1932–33.

(a) *Stevenson Screen.*

Thermometer.	Identification Number.	Type.	Range.	Dates when in Use.	Correction for Scale Error.							
Dry Bulb	M.O. 7	Hg	240° A. to 330° A.	July 1/32–Nov. 21/32	At 253° A.	At 263° A.	At 273° A.	At 283° A.	At 293° A.	At 303° A.	At 313° A.	At 323° A.
					−0·2	−0·2	−0·1	−0·1	−0·1	−0·2	−0·2	−0·2
	N.P.L. 32/20723	Spirit	−50° C. to +10° C.	Nov. 21/32–Apr. 8/33	At −39° C.	At −20° C.	At −10° C.	At 0° C.	At 10° C.			
					+0·2	+0·2	0·0	0·0	0·0			
	M.O. 7	Hg	240° A. to 330° A.	Apr. 8/33–Aug. 31/33	As above.							
Wet Bulb	M.O. 10	Hg	240° A. to 330° A.	Throughout period when such temperatures were taken.	At 260° A.	At 280° A.	At 290° A.	At 300° A.	At 310° A.			
					0·0	0·0	−0·1	−0·1	−0·1			
Maximum	No. 20756	Hg	−40° C. to +25° C.	July 1/32–Aug. 8/32	At −39° C.	At −20° C.	At −10° C.	At 0° C.	At 10° C.	At 20° C.		
					0·0	0·0	0·0	0·0	0·0	0·0		
	No. 20755	Hg	−40° C. to +25° C.	Aug. 8/32–Feb. 15/33	At −39° C.	At −20° C.	At −10° C.	At 0° C.	At 10° C.	At 20° C.		
					0·0	0·0	0·0	0·0	0·0	0·0		
	No. 20756	Hg	−40° C. to +25° C.	Feb. 15/33–Aug. 31/33	As above.							
Minimum	No. 21035	Spirit	230° A. to 313° A.	July 1/32–Nov. 16/32	At 233° A.	At 253° A.	At 263° A.	At 273° A.	At 283° A.	At 293° A.	At 303° A.	
					+1·0	0·0	0·0	0·0	0·0	0·0	0·0	
	No. 20757	Spirit	−55° C. to +10° C.	Nov. 16/32–May 20/33	At −39° C.	At −20° C.	At −10° C.	At 0° C.	At +10° C.			
					0·0	0·0	0·0	0·0	0·0			
	No. 21035	Spirit	230° A. to 313° A.	May 20/33–Aug. 31/33	As above.							

TABLE 2 (*continued*).

(b) *Ship's Screen, Grass Minima, and Assmann Thermometers.*

Thermometer.	Identification Number.	Type.	Range.	Dates when in Use.	Correction for Scale Error.						
Dry Bulb in Ship's Screen	33475/30	Hg	−15° F. to +115° F.	Aug. 1/32–Nov. 21/32	At 12° F.	At 32° F.	At 62° F.	At 82° F.	At 112° F.		
					−0·1	0·0	0·0	0·0	0·0		
	20722	Spirit	−50° C. to +10° C.	Nov. 21/32–May 4/33	At −39° C.	At −20° C.	At −10° C.	At 0° C.	At 10° C.		
					+0·2	+0·2	0·0	0·0	0·0		
	33475/30	Hg	−15° F. to +115° F.	May 4/33–Aug. 31/33	As above.						
Grass Minimum	M.O. 13	Spirit		July 29/32–Nov. 21/32	At 32° F.	At 42° F.	At 52° F.	At 62° F.	At 72° F.		
					0·0	0·0	0·0	+0·1	+0·1		
	Z. 3825	Spirit	−60° C. to 0° C.	Nov. 21/32–May 29/33	At −60° C.	At −40° C.	At −20° C.	At −10° C.	At 0° C.		
					+0·5	0·0	−0·5	0·0	0·0		
	M.O. 8	Spirit	230° A. to 315° A.	May 29/33–Aug. 31/33	At 234° A.	At 253° A.	At 263° A.	At 273° A.	At 283° A.	At 293° A.	At 303° A.
					−0·6	−0·2	−0·2	0·0	0·0	0·0	0·0
Assmann Dry	20727	Hg	−40° C. to +20° C.	Throughout year.	At −39° C.	At −20° C.	At −10° C.	At 0° C.	At 10° C.	At 20° C.	
					−0·1	−0·1	−0·1	0·0	−0·1	−0·1	
Assmann Wet	20729	Hg	−40° C. to +20° C.	Throughout period when wet bulb temperatures taken.	At −39° C.	At −20° C.	At −10° C.	At 0° C.	At 10° C.	At 20° C.	
					−0·1	−0·1	0·0	0·0	0·0	0·0	

the winter months from November to March inclusive, and a modification of the normal procedure had to be adopted during these months in order to determine the hourly values from the records.

The single pen distant reading thermograph was a daily subsidiary thermograph which had the recording mechanism indoors connected to the bulb in the small ship's screen by a Bourdon tube. In this manner the clock was never subject to the extremes of temperature of the winter months and never ceased to function. The distant reading thermograph only went out of action when the temperature fell to about $-40°$ C. and the mercury in the capillary became frozen, but on practically all occasions when this occurred the bimetallic thermograph in the Stevenson screen continued to function.

The thermograph was a good instrument with which to work. It was particularly sensitive throughout its range of temperature and had an open scale. Its scale value remained uniform except during the winter months, and here again a modification of the normal procedure had to be undertaken during these months whenever recourse had to be made to these records for hourly values of the temperature.

During the periods when the bimetallic thermograph in the Stevenson screen was out of action and recourse had to be made to the records of the distant reading thermograph for the hourly values of temperature, it was assumed that the curve of temperature on the distant reading thermograph gave the most probable course of temperature at the site of the Stevenson screen. Consequently the control temperatures used in evaluating the hourly values of temperature from the distant reading thermograph were the control temperatures taken in the Stevenson screen and not in the ship's screen. In this manner all the hourly values of temperature as published refer to the eight daily control temperatures taken in the Stevenson screen.

(d) *Thermometers.*—All the thermometers in use at Fort Rae had previously been tested at the National Physical Laboratory. The particulars of the various thermometers in use, together with the correction for the scale error as given by the N.P.L. certificates, have been entered in Table 2.

Spirit thermometers had to be placed in the screens at the beginning of the winter, because the temperature fell too low to be read on the scale of the mercury thermometers. The spirit thermometers had a lower range of temperature.

The thermometers in the screen were under constant check throughout the year for any errors occurring. During the morning and the evening, when the maximum and minimum thermometers were read and reset, they were checked against the dry bulb thermometer in the screen. Thus, twice a day these three thermometers were checked against each other. Usually when errors occurred, they always occurred in the maximum or minimum thermometers, and these were rectified before the thermometers were reset.

In addition, the dry bulb thermometer in the screen was checked by hanging the Assmann psychrometer on the outside of the screen, and reading the dry bulb thermometer of the psychrometer and the dry bulb thermometer in the screen directly after each other. This method of comparison was made on 193 occasions during the year at temperatures ranging from $-30°$ C. to $+25°$ C. The following table gives the mean difference between the readings of the dry bulb thermometer in the screen and the Assmann dry bulb thermometer in various ranges of temperature.

TABLE 3.—MEAN DIFFERENCE BETWEEN DRY BULB THERMOMETER IN SCREEN AND ASSMANN DRY BULB THERMOMETER.

Temperature Interval.					
30 to 20·1° C.	20 to 10·1° C.	10 to 0·1° C.	0 to $-9·9°$ C.	-10 to $-19·9°$ C.	-20 to $-30°$ C.
$-0·1°$ C.	$-0·1°$ C.	$-0·1°$ C.	$-0·1°$ C.	0·0° C.	$+0·2°$ C.

The wet bulb thermometer in the screen was also checked with the dry bulb thermometer on each occasion when the linen and wick were changed. On all occasions when the Assmann psychrometer was used outside the screen, the wet bulb thermometer of the psychrometer and the wet bulb thermometer in the screen were read directly after each other.

The grass minimum thermometer was placed in the screen with its bulb downwards during the day, and this thermometer was checked in the screen with the dry bulb thermometer before it was set for the night.

These daily comparisons gave a good and frequent check on the behaviour of the thermometers throughout the year, and without entering into further details it can be stated that the temperatures above $-20°$ C. are correct to within $\pm 0{\cdot}2°$ C. and below $-20°$ C. to within $\pm 0{\cdot}3°$ C.

(e) *Method of taking temperature observations. The Stevenson screen.*—The screen was visited eight times daily at intervals of three hours, commencing at 2h. On each occasion the temperature of the dry and wet bulb thermometers and the temperature then showing on the thermograph chart were immediately read, noted, and checked. In addition, at 8h daily the pen of the thermograph was depressed, the temperature and the time being noted. Thus, on each weekly thermograph chart there were six time marks exclusive of the end points of the record, which corresponded to the times of starting and ending of the record.

The weekly thermograph chart was changed at about 8h on the Monday.

At 8h daily the maximum and minimum thermometers and the grass minimum thermometer were read, noted, and checked. The maximum and minimum thermometers were then reset and checked with the dry bulb thermometer and against one another.

At 17h daily the maximum and minimum thermometers were again read, noted, checked, and reset. The grass minimum thermometer was checked with the dry bulb thermometer in the screen before setting outside for the night.

The ship's screen.—After the 2h, 8h, 14h, and 20h observations had been made in the Stevenson screen, the observer visited the ship's screen and noted and checked the temperature of the thermometer suspended alongside the distant reading thermograph bulb. The observer immediately afterwards walked inside the main station and noted the reading on the thermograph chart. At 11h and 23h the pen of the distant reading thermograph was depressed, giving two time marks exclusive of the two end points, whose corresponding times were known. The chart was changed at about 8h daily.

(f) *Method of reducing the thermograph records. The Stevenson screen weekly thermograph.*—It has been stated that on each weekly sheet there were altogether eight time marks at 24-hourly intervals, the temperature corresponding to each mark being known. There were also seven other observations per day at three-hourly intervals which corresponded to known control temperatures.

By means of a celluloid scale divided into hourly intervals fitting the chart, and by the aid of the time marks, the curve could be read at the exact hours. The thermograph clock kept exceedingly good time throughout the year, and on the few occasions when the rate of the clock changed, it was easy to mark the curve by a series of dots corresponding to the exact hours. Two independent sets of readings of the curve were taken, no pair of readings being allowed to pass if they differed by more than $0{\cdot}1°$ C.

A comparison of the 56 control values during the week with the corresponding curve readings gave the error of the thermograph. From the commencement of the records up to 1932 November 21 the differences between the control readings and those for the curve remained remarkably steady for each chart, so that a mean correction was applied. A few incorrect temperature readings were noted and omitted in this manner.

After 1932 November 21 and until 1933 April 7 it was found that the difference between the control and the curve readings did not remain steady throughout the

56 observations for each chart. These differences were, therefore, plotted against time, and a smooth curve drawn through the resulting points. From the smooth curve a correction was read for each hour, which had to be applied to the curve reading. In this manner, also, incorrect temperature readings were noted and omitted.

After 1933 April 7 a mean correction for each chart was applied.

The distant reading thermograph.—On each daily thermograph chart there were four points whose times and corresponding temperatures were known, so that it was comparatively easy to mark the whole curve by dots corresponding to the exact hours. Two independent sets of readings were taken, and no pair of readings was allowed to pass if they differed by more than 0·1° C. If the difference was greater than 0·1° C. an independent set of readings was again taken.

It has been stated that the control temperatures as taken in the ship's screen differed in the mean by very small amounts from the control temperatures in the Stevenson screen, though at times there were real differences of the order of 2° C. In the absence of a temperature record in the Stevenson screen, it was decided that the course of temperature in the interval of three hours between the control temperatures at the Stevenson screen could best be represented by the curve of the distant reading thermograph. In this manner for each daily chart of the distant reading thermograph there were eight control temperatures taken in the Stevenson screen. These eight control temperatures were compared with the corresponding readings taken from the distant reading thermograph, and the difference gave the correction to be applied to the distant reading thermograph values in order to obtain the most probable value of temperature at the site of the Stevenson screen. These differences were plotted against time, and a smooth curve drawn through the resulting points. From the resulting curve a correction was read at each hour of the day which had to be applied to the curve reading.

In the majority of cases in which recourse had to be had to this method the resulting curve was a straight line giving a steady correction which could be applied throughout the day, but there were a few cases in the winter in which the correction was variable during the day. In this manner a set of 24-hourly values of temperature was obtained, and only those values which could not be obtained from the thermograph in the Stevenson screen were entered in the final published hourly values.

2. ANNUAL VARIATION OF TEMPERATURE

The mean monthly temperatures are based upon hourly values of temperature which are available for twelve months during 1882–83, and for fourteen months during the year 1932–33 (see Vol. II, Tables 24–37). The monthly values have been entered in Table 4, in which the July and August values for 1932–33 are the direct means of July 1932, July 1933, and August 1932, August 1933 respectively.

TABLE 4.—MEAN MONTHLY TEMPERATURES.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
1882–83	−32·67	−23·56	−22·07	− 7·07	2·38	10·82	16·17	13·61	6·90	0·34	−12·59	−26·22
1932–33	−31·12	−30·48	−19·59	−10·65	3·49	10·76	16·24	16·87	7·15	−3·47	−19·82	−24·86
Mean	−31·89	−27·02	−20·83	− 8·86	2·93	10·79	16·21	15·24	7·03	−1·57	−16·21	−25·54

The values of temperature for the corresponding months of the two years show, on the whole, small differences during the summer and generally larger differences during the winter months from October to April.

The maximum mean monthly temperature based on the two years' observations occurs during July, and the minimum mean monthly temperature during January. The mean monthly values for the two years can be expressed by the formula *

$$T = -6{\cdot}48 + 23{\cdot}76 \sin (30t + 247{\cdot}5) + 1{\cdot}11 \sin (60t + 283{\cdot}3),$$

where t is the time in months reckoned from oh. on January 1.

The mean monthly values of temperature for the two years have been plotted in fig. 1, and the resulting points have been joined by a smoothed continuous curve.

Now Angot † has calculated the total heat received during each month at all ten degrees of latitude from the equator to the pole, using various values of the atmospheric absorption, his unit being "the quantity of heat which falls on unit horizontal surface at the equator during an equinoxial day, supposing the sun to be at its mean distance from the equator and neglecting atmospheric absorption." For the purpose of this discussion the absorption coefficient 0·7 has been used, and the values have been determined for each month of the year at a latitude 63° N., corresponding to the latitude of Fort Rae. Table 5 shows the total insolation received in each month at 63° N.

Table 5.—Total Insolation received at 63° N.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
0·1	1·1	4·7	9·9	14·9	17·1	15·7	11·2	6·0	1·8	0·2	0·1

These values of the insolation have also been plotted in fig. 1 and the resulting points have been joined by a dotted curve.

From the two curves in fig. 1 it is seen that the temperature follows the insolation during the early months of the year, but the maximum of temperature is attained in July about a month after the maximum of insolation. The insolation falls steadily after it has reached its maximum, and practically ceases altogether from November to January. The temperature, however, falls steadily from its maximum in July to its minimum in January, the rate of fall being equally as great during the period of little insolation in November to January as during the preceding months from August to November.

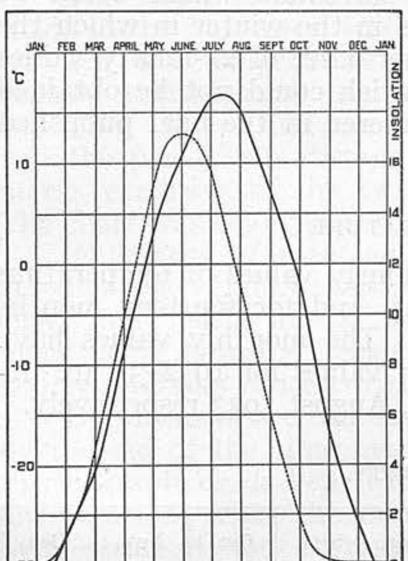


Fig. 1.—Annual variation of temperature and insolation at Fort Rae.

The annual course of temperature and insolation for Fort Rae can be represented by the following expressions:—

$$\text{Insolation} = 6{\cdot}9 + 8{\cdot}59 \sin (30t + 281{\cdot}4) + 1{\cdot}67 \sin (60t + 113{\cdot}7),$$

$$\text{Temperature} = -6{\cdot}48 + 23{\cdot}76 \sin (30t + 247{\cdot}5) + 1{\cdot}11 \sin (60t + 283{\cdot}3),$$

where t is the time in months reckoned from oh. on January 1.

In the expression for the annual variation of temperature at Fort Rae the amplitude of the first component is large compared with the amplitude of the second component, so that the phase is more or less given by the phase of the

* This formula is based on the assumption that the months are of equal length and that the mean values for the months are appropriate to the midpoints of the months. The errors arising from these assumptions are discussed in a paper by E. G. Bilham entitled "The Use of Monthly Mean Values in Climatological Analysis," in *Quart. J. R. Met. Soc.*, vol. xliv, p. 41 (1918). In the above formula, to get the January value one puts $t = \frac{1}{2}$, to get the February value one puts $t = 1\frac{1}{2}$, etc.

† Angot, Paris, *Annales du Bureau Cent. Met. de France*, 1883.

first component. The temperature thus lags behind the insolation by 33·9° or approximately 34·4 days.

Hann,* when analysing the mean annual temperature variation for a number of stations in the same latitude having land and sea climates, obtains the following results for 60° N.:—

"Annual Temperature Variation and Insolation for 60° N. (Hann).

Sea Climate . .	$4{\cdot}22 \sin(30t+238{\cdot}6)+0{\cdot}77 \sin(60t+29{\cdot}4)$.
Land Climate . .	$23{\cdot}93 \sin(30t+256{\cdot}3)+1{\cdot}34 \sin(60t+311{\cdot}3)$.
Insolation . . .	$9{\cdot}02 \sin(30t+281{\cdot}6)+1{\cdot}28 \sin(60t+114{\cdot}2)$."

From a consideration of the phases it is seen that the temperature of a land station lags behind the insolation by 25·3° or 25·7 days, whereas the lag associated with a sea station amounts to 43·0° or 43·6 days. The lag of 34·4 days shown by the temperature at Fort Rae is intermediate between the lag shown by a typical land and sea station in latitude 60° N.

Hann also shows that for a land station the ratio of the second to the first coefficient in the harmonic terms is very small, in the mean 0·05. The second term has little influence on the course of the annual temperature. For a sea station, however, the ratio of the coefficients is greater, in the mean 0·16, so that the second term has an appreciable effect upon the course of the annual temperature. The ratio of the coefficients for Fort Rae is 0·05, so that as regards amplitude the temperature behaves like that of a land station.

3. THE DIURNAL VARIATION OF TEMPERATURE

(a) *Diurnal inequalities.*—The diurnal inequalities of temperature for the months and seasons of the years 1882–83 and 1932–33 respectively are given in Table 1, Vol. II.

It may be remarked here that in these tables the time used for the results of the year 1882–83 was the local mean time of Old Fort Rae, but during 1932–33 the time used was the zonal mean time of the 120th meridian west of Greenwich. The local mean time of Old Fort Rae was 7h 44m slow on Greenwich mean time, whereas the zonal mean time used during 1932–33 was 8 hours slow on Greenwich. Thus the local mean time used at Old Fort Rae during 1882–83 was in advance of the zonal mean time used at Fort Rae during 1932–33 by 16 minutes. In forming the diurnal inequalities of the combined years at the exact hours, account should therefore be taken of the differences in the time used at the two places, but as the time difference is small, and as the inequalities are slowly changing variables during the day, it has been considered that the combination of the inequalities for 1882–83 at the exact hours of local mean time with the inequalities for 1932–33 at the exact hours of zonal mean time will only affect the validity of such a combination very slightly indeed. This procedure, though not exact, has been carried out to obtain the inequalities of temperature for the combined years. These remarks apply equally to the diurnal inequalities of pressure. The inequalities for the months and seasons of the combined years are also entered in Table 1, Vol. II.

The inequalities for the year 1932–33 and for the combined years have been plotted against time in fig. 2 (*a*), (*b*), and the resulting points joined by a smooth curve, the months having similar solar conditions being plotted in juxtaposition.

From the figures it is seen that even two years' observations give fairly smooth curves, except for the winter month of December where the amplitude is small

* Hann, Berlin, *Lehrbuch der Meteorologie*, p. 98. The phases of the first and second components have been decreased by 15°, 30° respectively in order that the time may be reckoned from 0h. on January 1.

and the non-periodic changes large. The inequalities for all months show a normal type of variation, with positive values during the day and negative values during the night.

The amplitude of the diurnal variation of temperature is smallest in December, after which it increases rapidly to attain its maximum value in one of the spring months, March or April. After the spring the amplitude of temperature decreases slowly during the summer, and then more rapidly, reaching its minimum value again in December. The amplitudes of the diurnal variation of temperature for each

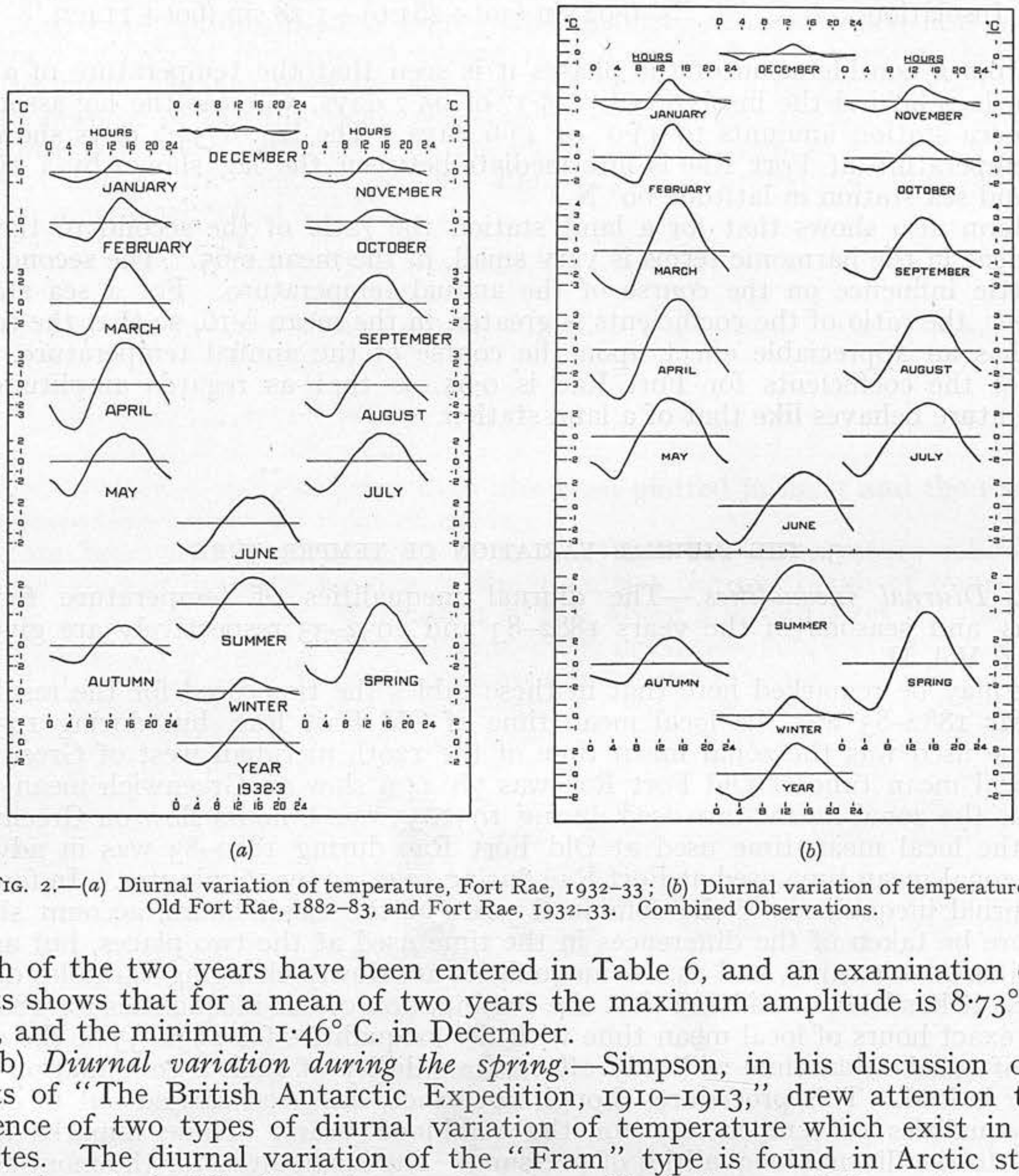


FIG. 2.—(a) Diurnal variation of temperature, Fort Rae, 1932–33; (b) Diurnal variation of temperature, Old Fort Rae, 1882–83, and Fort Rae, 1932–33. Combined Observations.

month of the two years have been entered in Table 6, and an examination of the results shows that for a mean of two years the maximum amplitude is 8·73° C. in April, and the minimum 1·46° C. in December.

(b) *Diurnal variation during the spring.*—Simpson, in his discussion of the results of "The British Antarctic Expedition, 1910–1913," drew attention to the existence of two types of diurnal variation of temperature which exist in polar climates. The diurnal variation of the "Fram" type is found in Arctic stations and is characterised by having a maximum amplitude in one of the spring months. The "McMurdo" type of diurnal variation has a maximum amplitude in one of the summer months. From the statements in the preceding section it is seen that the diurnal variation of temperature at Fort Rae is of the "Fram" type.

Simpson, when discussing the "Fram" type of daily variation of temperature, showed that the explanations suggested by both Mohn and Meinardus are insufficient in themselves to give an adequate account of the amplitudes experienced. Both Mohn and Meinardus, in their discussion of the "Fram" type, attempted to give an explanation of the low amplitudes of temperature variation during the summer months, but Simpson showed that it was not the low values in the summer, but the high values of the amplitude in the spring that needed explanation.

Simpson showed that it is the amplitude of radiation income and not the total radiation income which is a factor of great importance when considering the temperature amplitudes. After plotting the temperature amplitudes against the amplitudes of radiation income during the spring and summer months for a number

Table 6.—Amplitudes of the Diurnal Variation of Temperature.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
1882	..	..	..	..	..	..	..	..	5·39	3·06	2·11	2·11
1883	3·35	5·59	9·43	8·82	7·91	7·16	6·77	6·17	..	..	..	..
1932	..	..	..	..	..	..	5·02	5·55	5·28	2·08	2·51	0·81
1933	2·04	4·39	7·17	8·65	6·08	5·55	6·41	6·88	..	..	..	..
Mean	2·69	4·99	8·30	8·73	6·99	6·35	6·24*	6·19*	5·33	2·57	2·31	1·46
Combined Years	2·53	4·99	8·25	8·74	6·94	6·34	6·18	6·15	5·33	2·52	2·26	1·39

* Mean determined from expression Mean $=\frac{1}{2}\left[1883+\frac{1932+1933}{2}\right]$.

of stations in the Arctic and Antarctic, he showed that, except for small differences, the relation between temperature amplitude and radiation amplitude was linear, and the only points which departed from this linear relationship were the points corresponding to the spring for stations of the "Fram" type. It was these anomalous positions in the amplitude of temperature for the spring which called for an explanation.

The amplitudes of the radiation income have been calculated for Fort Rae, latitude 62° 50′ N., by the method given by Mohn * in the discussion of the results of the Norwegian North Polar Expedition. This method takes account of the energy received directly from the sun and that diffused by the illuminated atmosphere. The values obtained for Fort Rae are entered in Table 7.

The last row in this table also contains the values of mean temperature amplitudes taken from Table 6. The values of the radiation amplitude have been plotted against the corresponding values of the temperature amplitude in fig. 3.

An examination of the figure shows that nine out of the twelve points lie closely around a straight line which is drawn in the figure, so that, according to Simpson's original results, the amplitude of temperature and the amplitude of radiation income have a linear relationship. The points for the spring months, however, do not lie so near the line, and these have been joined by a separate curved line. The greatest departure from the linear relationship occurs in March and April.

Thus, as the amplitude of the radiation income increases with the advance of the season, so also does the temperature amplitude, except for the spring months February, March, and April, which show an anomalous feature in having an increased temperature amplitude.

In order to account for this increased temperature amplitude during the spring months it is appropriate to quote a little from Simpson's discussion of the meteorological results of the British Antarctic Expedition.†

* H. Mohn, *Norwegian North Polar Expedition, 1893–1896*, vol. vi, pp. 588–597.

† Simpson, *British Antarctic Expedition, 1910–13*, pp. 57–58.

"Under the same conditions of solar radiation, the temperature of the air will depend entirely on the nature of the ground upon which the radiation falls, for the radiation does not warm the air directly, but only by first warming up the ground on which it falls. . . .

TABLE 7.—SOLAR RADIATION IN GM. CAL. PER MIN. PER SQ. CM. OF HORIZONTAL SURFACE AT FORT RAE, 62° 50′ N.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Noon	Sun Horizontal Radiation . .	·028	·203	·569	·993	1·288	1·406	1·345	1·107	·730	·323	·059	·010
	Sky Horizontal Radiation . .	·160	·263	·393	·550	·660	·690	·677	·614	·420	·307	·192	·127
	Total . .	·188	·466	·962	1·543	1·948	2·096	2·022	1·721	1·150	·630	·251	·137
Mid-night	Sun Horizontal Radiation . .	0	0	0	0	0	0	0	0	0	0	0	0
	Sky Horizontal Radiation . .	0	0	0	0	·016	·047	·033	·003	0	0	0	0
	Total . .	0	0	0	0	·016	·047	·033	·003	0	0	0	0
	Radiation Amplitude . . .	·188	·466	·962	1·543	1·932	2·049	1·989	1·718	1·150	·630	·251	·137
	Mean Temperature Amplitude * .	2·69° C.	4·99° C.	8·30° C.	8·73° C.	6·99° C.	6·35° C.	6·24° C.	6·19° C.	5·33° C.	2·57° C.	2·31° C.	1·46° C.

* Compare Table 6.

"Let us now consider the temperature of the surface of the Barrier during a bright sunny day and the following night. During the day-time the sun shines on the snow, and although a large proportion is reflected, some is absorbed. As the conductivity of snow is very small, this heat is not conducted downwards to any considerable depth, but is all retained near the surface; also, on account of its small density the thermal capacity of snow is small. Thus a very little heat being retained near the surface, and acting on a substance of small heat capacity, raises the temperature of the snow near the surface appreciably. During the night the snow surface radiates heat to the clear sky and its temperature falls, but these conditions, which caused its temperature to rise while the sun was shining, now act in the opposite direction. On account of the small heat capacity of the snow a small loss of heat by radiation lowers the temperature considerably, and as the low conductivity prevents heat being conducted from below, the temperature of the surface may fall very greatly during a clear night."

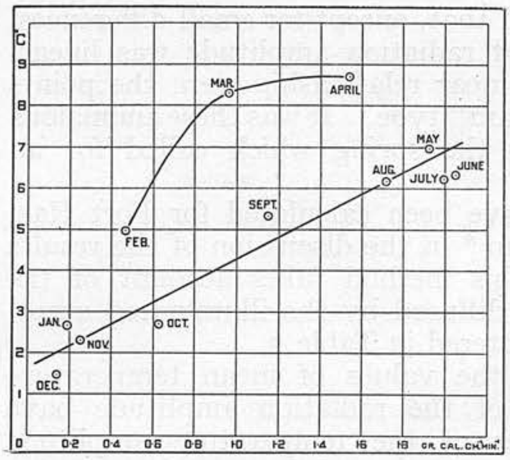


FIG. 3.—Amplitude of temperature plotted against amplitude of radiation income.

From these statements it is seen that a loose covering of snow will tend to increase the temperature amplitude, especially during the spring, the period of increasing solar energy.

It is extremely difficult to obtain a measurement of the depth of snow which is representative of an area, owing to the fact that if a position is chosen which is fairly well exposed, the wind disperses the snow and there is a deficiency of snow at the site. A sheltered spot is also a site in which the snow accumulates in large drifts several feet high. This same difficulty occurred at Fort Rae, where in the winter there existed drifts about 15 feet high and, at the same time, exposed rock. The snow over the North Arm of the lake was hard packed, but in the bush, which extends for several miles around the lake, the snow was loose and in places very deep. The snow-covering in the bush would be more representative of the snow-covering of the whole area, but no measurements of the depth of snow were taken in the bush. Here, however, after the commencement of snowfall in October, the depth increased, reaching its maximum depth of an average of about 2 feet to 2 feet 6 inches in March to early April. The melting of the snow was more visible during the last week in April and the month of May.

Measurements of snow depth at different times on the lake confirm this opinion, but the site was not a good one, being too exposed from the north and slightly sheltered from the south. The measurements, however, do show increasing depths: 10 cm. by the end of November, 13 cm. by the end of January, 20 cm. by March 2, 27 cm. by March 30, 25 cm. by April 19, and only 8 cm. by May 4. By May 10 most of the snow had disappeared from the small island on which the station was situated, and by May 20 the main channel below the ice in the North Arm of the lake showed signs of breaking.

At Rae, therefore, the condition of the surface-covering was that of loose snow of increasing depth up to the third week of April, after which the snow melted rapidly during the fourth week of April and the month of May. This loose covering of snow, during the spring months of increasing solar radiation, would, as pointed out by Simpson, help to give an increased amplitude of temperature during these months.

During the last week of April and the month of May the nature of the ground-covering changed rapidly at Fort Rae; the snow melted, exposing the rock and earth, though the latter remained frozen near the surface until the second week in June. The month of May, therefore, was the first month in which the loose snow-covering had either disappeared or become extremely thin, apart from residual drifts. It is also the first month during the period of increasing solar energy which shows a temperature amplitude in conformity with the linear relationship shown in the diagram.

Simpson shows that it is the consequence of this change in the surface conditions which accounts for the return of the temperature amplitude to the linear relationship. During the day the heat absorbed by the earth's surface is not now retained in a shallow thickness of snow, but owing to the higher conductivity of the rock and earth is conducted downwards into the mass. In addition, the rock and earth have a higher thermal capacity than that of loose snow, so that under the same conditions of incoming solar radiation, the rise in temperature of the surface of the earth will be much less. These factors will tend to keep the surface temperatures lower than if the surface was covered by a loose layer of snow. During a night of radiation the heat stored in the rock and earth will be conducted outwards from below and will prevent the surface temperatures from falling as low as they would have done had the surface been covered by a loose layer of snow through which the heat can penetrate slowly. Low radiation temperatures are thus prevented. The change of the surface-covering which occurs at Fort Rae in May will account partially for the return of the temperature amplitude to the linear relationship.

Since the publication of Simpson's work another factor has been shown to play an important rôle in accounting for the "Fram" type of diurnal variation. Kidson * has stated that, "Under any particular set of conditions as regards radiation from the sun and the state of the atmosphere, a ground surface will tend to reach a certain mean temperature at which it is in a state of equilibrium, the total amount of heat lost by radiation and conduction being equal to that received. The diurnal variation of temperature will depend upon the relation of this equilibrium temperature to that of the general mass of air. If the air temperature is higher, then a cold layer must form at the surface for at least a large portion of the day, and there will be no tendency for the heat to be carried away by convection during this time. The greater the difference, the more stable and intense will the cold layer be. On the other hand, if the air be the colder, then heat will be carried away readily from the surface by convection. In the first case the exchange of heat by conduction and convection between the

* E. Kidson, Melbourne, *British Antarctic Expedition, 1907–1909.* Report on the Scientific Investigations.

surface and the air as the amount of solar radiation varies during the day is confined to a shallow layer. The diurnal variation of temperature, therefore, is large compared with that of the solar radiation. In the second case the surface imparts heat to large masses of air, and the diurnal variation for the same change in solar radiation is small.

"Over the Barrier, since most of the sun's heat is reflected back into space, the equilibrium temperature is very low, lower in fact than the temperature of the air even in summer. . . . In some localities the thermal characteristics will approach those of the Barrier during the spring months, and the diurnal variation will be large. Then, at a later date, owing to the removal of the snow-covering from land and sea ice, the nature of the surface will change, its temperature will rise, and the diurnal variation will be more like that over the open sea. The 'Fram' type of variation will thus be produced. . . .

"The above is, in effect, the same as Simpson's explanation of the diurnal variation, except that he does not refer to the importance of the temperature of the general mass of air, as compared with that which can be maintained by the earth's surface at the observing station."

Thus the amplitude of the diurnal variation of temperature will depend, not only upon the thermal characteristics of the surface, but also upon the vertical extent of the air mass which is influenced by convection and conduction of heat from the surface. Sverdrup, in the meteorological discussion of the Norwegian Polar Expedition of the *Maud*,* confirmed this from the detailed data which he had taken, and he showed that this air, which was heated by convection during the day-time, increases in thickness as the season advances after the return of the sun. He deduced, from his data, the formula

$$A_T = A_R \frac{1000}{H},$$

where A_T is the amplitude of the diurnal variation of temperature in degrees centigrade, A_R is the amplitude of the incoming radiation in gm. cal. per square cm. per min., and H is the thickness in metres of the convection layer which takes part in the diurnal oscillation of temperature.

The available data collected at Fort Rae give no means of determining directly the height of the convection layer for the different months of the spring, but if the formula has a general application and if it can be applied to the amplitude of temperature and radiation at Fort Rae, it will give a method of determining a mean height of the convection layers for the spring months.

The results of the calculations, using the mean values of A_T for the spring months and the values of A_R calculated according to Mohn's method, are given in Table 8.

TABLE 8.—VERTICAL EXTENT OF CONVECTION LAYERS AT FORT RAE.

Month.	A_T. °C.	A_R. gr. cal./cm.^{2}/min.	$\frac{A_R}{A_T}$.	H. metres.	*Maud.* metres.
January	2·69	·19	·0706	71	..
February .	4·99	·47	·0942	94	130
March .	8·30	·96	·1157	116	130
April . .	8·73	1·54	·1764	176	180
May . .	6·99	1·93	·2761	276	270

The values of the thickness of the convection layer show a steady increase as the season advances and a rapid increase from April to May, the order of magnitude

* H. U. Sverdrup, Bergen, *The Norwegian North Polar Expedition with the "Maud," 1918–25.* Scientific Results. Vol. ii. "Meteorology," Part I, pp. 137–143.

of the convection layers for the months being similar to those obtained by Sverdrup * during the expedition with the *Maud*. For the purpose of comparison, the mean monthly values obtained by Sverdrup have been entered in the last column of the table, and the agreement is too close to be merely accidental. The heights indicate a rapid increase in the vertical extent of the convection layer which partakes in the diurnal oscillation of temperature after April, and, owing to this, the amplitude of the diurnal oscillation will decrease during May.

According to Sverdrup, the question whether the amplitude of temperature will increase or decrease is a question of the delicate balance which exists between the increment in the amplitude of the radiation income and the increment in the height of the convection layer. If this be expressed mathematically, then

$$dA_T \gtrless 0$$

according as

$$d\left(1000\,\frac{A_R}{H}\right) \gtrless 0,$$

that is, according as

$$dA_R \gtrless \frac{dH}{H}.$$

From January to April the inequality $dA_R > \frac{dH}{H}$ holds, so that the temperature amplitude will increase; but from April to May $dA_R < \frac{dH}{H}$, so that there will be a decrease in the temperature amplitude.

In conclusion, therefore, the explanations put forward by Simpson, Kidson, and Sverdrup seem to give an adequate explanation of the "Fram" type of diurnal variation of temperature which is experienced at Fort Rae.

(c) *The results of harmonic analysis*.—The results of the harmonic analysis of the monthly and seasonal mean diurnal inequalities for 1882–83 and 1932–33 are given in Table 9 (p. 34), but the analysis leads to no new results. The coefficient of the whole day period is greatest in one of the spring months, March or April, and least in December. The phase of the whole day period does not vary much throughout the year.

The amplitude of the half-day period is small, except in February 1883, and the phase angles are irregular. For the shorter periods the amplitudes are all small and the phase angles irregular.

4. THE EFFECT OF CLOUD AND WIND UPON TEMPERATURE

(a) *The effect of cloud and wind upon the mean daily temperature*.—In order to determine the effect of cloud and wind velocity upon the temperature of the air at the surface, all days in the period September 1 to August 31, for both years, during which the mean daily cloudiness based on 24-hourly values was zero to three-tenths, have been grouped together as clear days; similarly, all days in both years, during which the mean cloudiness based on 24-hourly values was eight-tenths to ten-tenths, have been grouped together as cloudy days. For the month of September 1932, however, 24-hourly values were not made, so that for this month the mean daily cloudiness has been based upon the eight standard observations per day.

These groups have been further subdivided according as the mean daily velocity of the wind lay between the limits 0 to 4·0 m/s, 4·1 to 7·4 m/s.

Table 10 gives the mean daily temperatures for the seasons during clear and overcast sky under these specified wind velocity limits, each month in the respective season being given equal weight in forming the mean daily temperature for that season.

* H. U. Sverdrup, Bergen, *The Norwegian North Polar Expedition with the "Maud," 1918–25*. Scientific Results. Vol. ii, "Meteorology," Part I, p. 141.

TABLE 9.—HARMONIC COEFFICIENTS OF THE DIURNAL INEQUALITY OF TEMPERATURE.

OLD FORT RAE, 1882–83. Latitude 62° 38′ 50″ N. Longitude 115° 48′ 41″ W.

Values of c_n, α_n in the series $c_n \sin(15nt + \alpha_n)$, t being Local Mean Time reckoned in hours from midnight.

Month and Season.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
	°C.	°	°C.	°	°C.	°	°C.	°
1882 September	2·46	239	·69	60	·13	71	·12	259
October	1·29	241	·57	65	·12	249	·04	277
November	·76	239	·46	63	·13	276	·03	46
December	·59	229	·36	87	·16	217	·15	83
1883 January	1·04	234	·68	53	·44	226	·21	54
February	1·89	219	1·16	51	·35	229	·08	291
March	4·30	223	·93	55	·23	56	·17	259
April	4·09	223	·55	47	·28	61	·07	264
May	3·76	237	·18	49	·15	23	·35	39
June	3·35	228	·30	236	·14	84	·05	56
July	3·30	232	·23	203	·16	78	·12	75
August	3·03	229	·27	60	·30	37	·04	117
Year . .	2·47	230	·44	59	·01	85	·04	32
Winter . .	1·06	227	·61	50	·26	231	·14	5
Equinox . .	3·01	230	·64	63	·21	53	·19	265
Summer . .	3·35	232	·03	166	·17	51	·13	53

FORT RAE, 1932–33. Latitude 62° 49′ 46″ N. Longitude 116° 4′ 3″ W.

Values of c_n, α_n in the series $c_n \sin(15nt + \alpha_n)$, t being Zonal Mean Time reckoned in hours from midnight.

Month and Season.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
	°C.	°	°C.	°	°C.	°	°C.	°
1932 July	2·49	223	·12	194	·09	19	·05	72
August	3·24	221	·44	61	·19	55	·04	359
September	2·58	228	·46	70	·14	43	·12	232
October	·96	219	·25	35	·07	269	·03	226
November	1·04	214	·34	57	·18	241	·06	19
December	·23	286	·16	35	·09	121	·11	16
1933 January	·82	210	·28	59	·12	217	·08	2
February	1·79	207	·68	41	·25	213	·05	61
March	3·41	216	·69	29	·10	224	·10	229
April	4·27	215	·39	75	·13	22	·02	15
May	2·90	229	·35	131	·28	38	·13	31
June	2·82	221	·27	204	·02	16	·07	13
July	3·21	226	·15	188	·08	357	·08	9
August	2·77	223	·25	91	·12	23	·04	88
Year . .	2·20	220	·27	61	·01	357	·01	9
Winter . .	·92	213	·36	48	·13	213	·07	21
Equinox . .	2·80	219	·42	50	·03	1	·06	226
Summer . .	2·89	224	·17	138	·13	34	·07	29
Combined Years	2·33	225	·35	60	·01	52	·03	23

Table 10.—Weighted Mean Daily Temperatures during Clear and Overcast Sky under Specified Limits of Wind Velocity.

Season.	Clear Days.				Overcast Days.			
	$0 \leqslant \overline{V} \leqslant 4{\cdot}0$ m/s.		$4{\cdot}1 \leqslant \overline{V} \leqslant 7{\cdot}4$ m/s.		$0 \leqslant \overline{V} \leqslant 4{\cdot}0$ m/s.		$4{\cdot}1 \leqslant \overline{V} \leqslant 7{\cdot}4$ m/s.	
	Number of Days.	Mean. °C.	Number of Days.	Mean. °C.	Number of Days.	Mean. °C.	Number of Days.	Mean. °C.
Spring .	33	−19·1	5	−16·0	15	−10·1	8	−11·6
Summer	30	10·3	6	12·1	31	9·0	28	8·6
Autumn	13	6·9	5	5·8	39	0·2	15	− 1·8
Winter .	55	−33·1	11	−29·8	41	−14·7	15	−16·1

It is noticed that for some of the seasons the number of days incorporated are few, so that not too much weight can be given to the mean values of temperature obtained from them. Certain observations on the results of the table can, however, be made.

The mean temperature of the air during the spring, summer, and winter is lower during days of clear sky with weak winds than during days of clear sky with strong winds. In the autumn there is only a small difference of temperature during clear days with weak or strong winds.

The mean daily temperature of the air in all seasons is higher during days of overcast sky with weak winds than during days of overcast sky and strong winds.

In the spring and winter the temperature of the air is lower during days of clear sky than during days of overcast sky under all conditions of wind velocity. This difference of temperature is exceedingly large in the winter.

In the summer and autumn, however, the temperature during clear days is higher than the temperature during overcast days under all conditions of wind velocity.

(b) *The effect of cloud and wind upon the diurnal variation of temperature.*—For the purpose of investigating the diurnal variation of temperature during clear and overcast sky, the same classification of days has been made for the two years,

Table 11.—Characteristics of Days of Clear and Overcast Sky under Specified Wind Velocities.

Season.	Velocity.	Clear Days.					Overcast Days.				
		Mean Temp.	Mean Cloud.	Mean Wind.	Temp. Amplitude.	Number of Days.	Mean Temp.	Mean Cloud.	Mean Wind.	Temp. Amplitude.	Number of Days.
	m/s.	°C.	tenths.	m/s.	°C.		°C.	tenths.	m/s.	°C.	
Spring .	0–2·0	−22·16	1·1	1·2	12·33	20	−10·32	8·5	1·8	7·27	4
Summer		13·77	1·9	1·5	9·24	8	8·84	9·0	1·5	4·16	11
Autumn		6·48	1·8	1·6	9·66	4	0·06	9·1	1·5	3·08	10
Winter .		−33·18	1·7	1·0	4·04	32	−13·15	9·0	1·2	1·50	21
Spring .	2·1 – 4·0	−14·48	1·5	2·8	10·63	13	−10·04	9·3	3·1	5·39	11
Summer		9·06	1·8	2·9	8·61	22	9·07	9·1	3·0	3·94	20
Autumn		7·06	2·2	3·1	7·48	9	0·20	9·1	2·9	2·07	29
Winter .		−32·98	1·4	2·8	3·11	23	−16·27	9·3	3·2	1·03	20
Spring .	4·1–7·4	−15·97	1·4	6·7	9·09	5	−11·62	9·3	6·3	5·79	8
Summer		12·12	2·2	4·7	7·87	6	8·62	9·2	6·3	3·34	28
Autumn		5·76	1·3	5·7	7·50	5	− 1·79	9·5	6·1	1·95	15
Winter .		−29·82	0·8	6·2	2·86	11	−16·10	9·3	6·4	1·73	15

except that the velocity limits have been taken from 0 to 2·0 m/s, 2·1 to 4·0 m/s, 4·1 to 7·4 m/s. The diurnal variation of temperature for all the groups has been entered in Table 2, Vol. II, and the characteristics of the groups of days have been entered in Table 11.

The diurnal inequalities given in Table 2, Vol. II, have been plotted against time in fig. 4 for the four seasons during clear and overcast days.

It is seen from the data given that, during clear and overcast days under all limits of wind velocity, the amplitude of temperature is greatest in the spring,

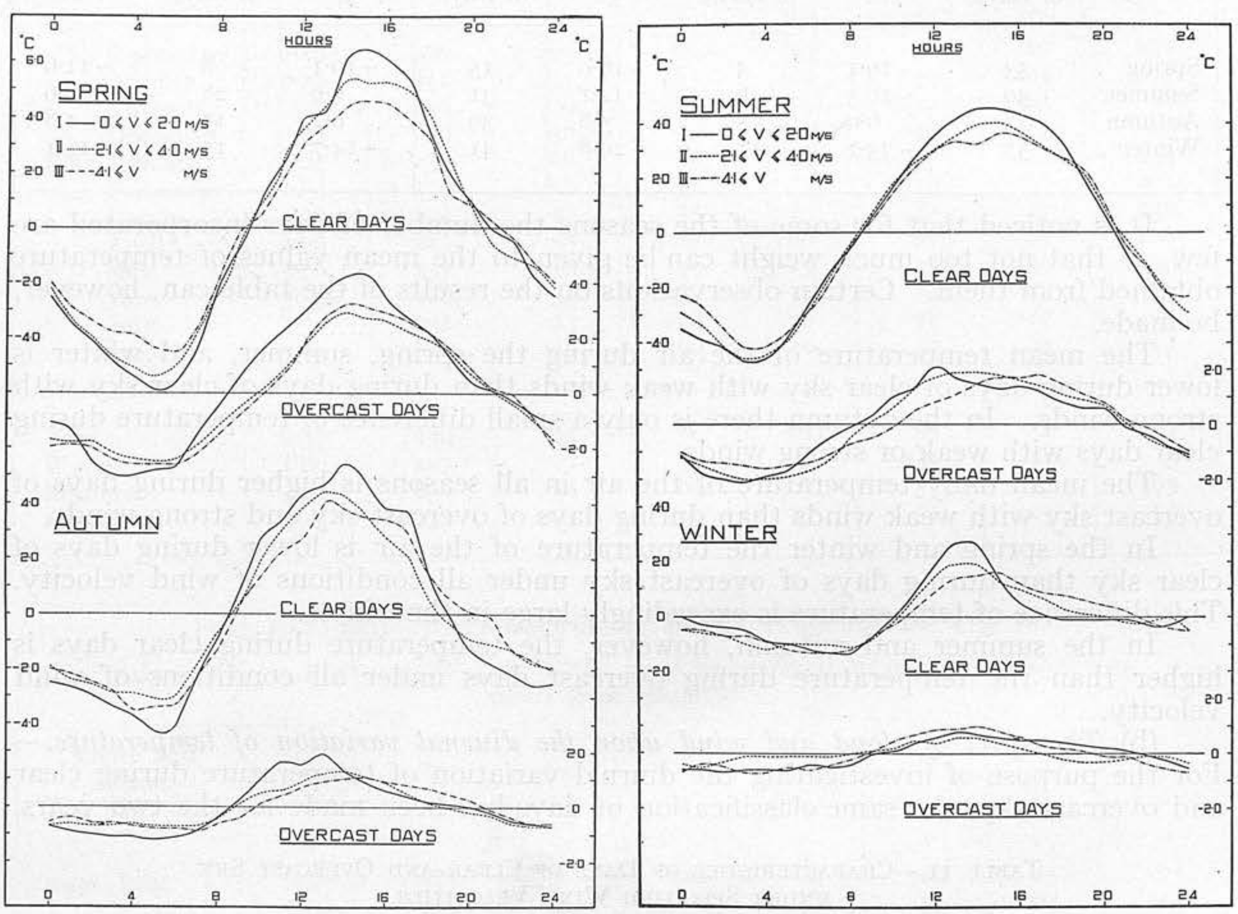


FIG. 4.—Diurnal variation of temperature during clear and overcast days under specified wind velocities.

decreasing through the summer and autumn to its minimum amplitude in the winter. The only anomaly to this is the amplitude of temperature during the summer and autumn on clear days for winds below 2·1 m/s, but it is to be noticed that the number of days in both these seasons is small, so that in all probability the anomaly is accidental.

The amplitude of temperature for all seasons under all limits of wind velocity is greater during clear days than during overcast days.

In fig. 5 the amplitudes of temperature have been plotted against the mean wind velocity, as given in Table 11, during clear and overcast sky for all seasons. The number of days which have been used to determine each point plotted has been entered in the figure at the side of the point.

The relation between the velocity of the wind and the amplitude of temperature appears to be linear from six out of the eight groups, and a straight line has been drawn through them. Two groups, namely, spring during overcast sky and autumn during clear sky, seem to depart slightly from the linear relationship, but the total numbers of days used for determining these two groups are decidedly smaller than the number of days which determines any of the other groups showing the linear relationship. It may be, therefore, that the two groups show an accidental anomaly, and that more days are required to determine the linear relationship.

The amplitude of temperature decreases more rapidly with increasing wind velocity during clear days than during overcast days.

(c) *The effect of cloud and wind upon the height of the convection layer in spring.*—If we assume that the formula given by Sverdrup between the amplitude of radiation income, the amplitude of temperature, and the height of the convection layer is applicable to Fort Rae, then it affords a means of determining the height of the convection layer during clear and overcast days in the spring under specified wind velocities.

The mean value of the radiation amplitude at Fort Rae for the two spring months, March and April, is 1·25 gm. cal./min./sq. cm. of horizontal surface. Using

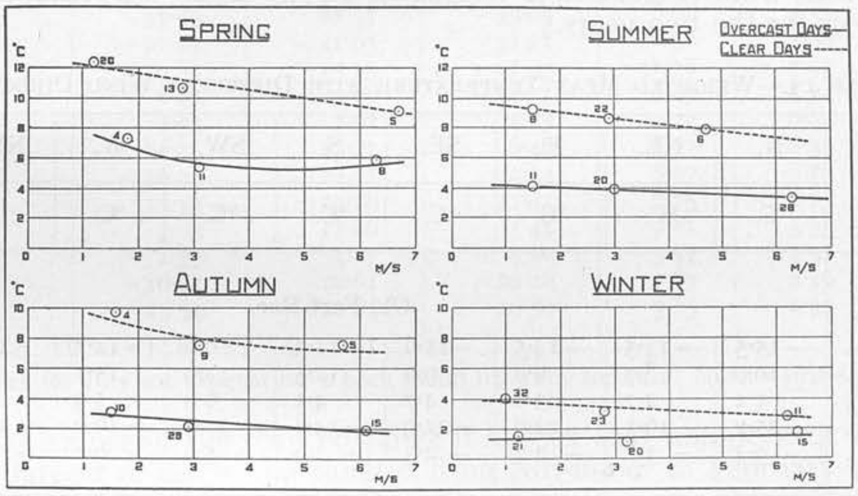


FIG. 5.—Amplitude of temperature plotted against mean wind velocity during clear and overcast sky.

this value for the radiation amplitude and the appropriate values of the temperature amplitude on clear days under specified wind velocities, the heights of the convection layers are obtained. These values have been entered in Table 12.

Sverdrup * states that Mosby, when discussing the radiation measurements, found the ratio between the amplitudes of the radiation income at overcast sky and clear sky to be 0·61 at the mean date April 1, so that if this ratio be also assumed at Fort Rae, then the amplitude of radiation income has the value 0·76 gm. cal./min./sq. cm. of horizontal surface during overcast sky. Using this value for the amplitude of radiation income and the appropriate values of the temperature amplitude under the specified wind velocities during overcast sky, the heights of the convection layers are obtained. These values have also been entered in Table 12.

TABLE 12.—HEIGHT OF THE CONVECTION LAYER IN THE SPRING DURING CLEAR AND OVERCAST SKY UNDER SPECIFIED WIND VELOCITIES.

Velocity Limits. m/s.	Clear Sky. H in Metres.	Overcast Sky. H in Metres.
0–2·0	102	105
2·1–4·0	118	141
4·1–7·4	137	131

* H. U. Sverdrup, Bergen, *The Norwegian North Polar Expedition with the "Maud," 1918–25*, vol. ii, "Meteorology," Part I, p. 151; H. Mosby, Bergen, *Norwegian North Polar Expedition, 1932*, vol. i, No. 7, "Sunshine and Radiation."

5. TEMPERATURE AND WIND DIRECTION

In order to determine the effect of the wind direction upon the surface air temperature, the mean temperature has been determined for eight directions of the wind, calms being treated separately.

The results have been based on the eight standard observations per day, taken at three-hourly intervals commencing at 2h, and the computation was originally carried out for each month for sixteen points of the wind. The data obtained, however, for the directions NNE., ESE., etc., were divided equally between the adjacent wind directions, and the final values for any season are the weighted means of the values for the months comprising that season. The year 1882–83 comprises the twelve months from September to August, while the year 1932–33 contains the thirteen months from August 1932 to August 1933. Table 13 contains the results of the analysis for the two years.

TABLE 13.—WEIGHTED MEAN TEMPERATURE WITH DIFFERENT WIND DIRECTIONS.

Year or Season.*	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
1882–83.	Old Fort Rae.								
Spring	−15·5	−13·5	−13·5	−11·6	(−11·3)	(+0·6)	(−12·7)	−14·7	−20·3
Summer	10·0	8·7	9·8	9·9	12·5	12·9	15·1	12·0	9·9
Autumn	1·2	2·7	3·8	4·7	4·1	6·6	5·9	2·9	0·7
Winter	−25·2	−16·1	−22·9	−22·9	−14·2	−10·1	−19·6	−23·6	−27·3
Year	− 9·4	− 1·8	− 2·2	− 2·3	+ 2·9	+ 5·0	− 0·2	− 8·3	−17·2
1932–33.	Fort Rae.								
Spring	−16·2	−14·8	−14·6	−12·0	−12·2	(−16·2)	−17·3	−18·1	−20·2
Summer	10·5	10·1	10·1	12·6	13·3	14·3	12·1	9·7	12·1
Autumn	0·3	− 3·0	− 0·5	4·4	2·3	5·5	0·7	1·6	1·8
Winter	−25·3	−23·6	−22·9	−26·2	−26·1	−27·5	−26·1	−25·6	−32·8
Year	−10·1	− 7·3	− 3·0	− 2·4	+ 2·3	− 1·1	−10·8	−10·0	−14·0

* Spring comprises the months March, April; summer May, June, July, August; autumn September, October; winter November, December, January, February. The values in the brackets are based on less than ten observations.

In the spring the warmest winds blow from S. to SE. and the coldest from NW. to N. In the summer the warmest winds blow from the SW. to W. and the coldest from the NE. During the autumn the warmest wind blows from the SW., though both years also show a secondary maximum of temperature for SE. winds. The lowest mean temperature occurs with winds from the N. to NE. The temperatures for the two winter periods do not show similar features. During the year 1882–83 the maximum temperatures occur for SW. winds, but the NE. winds show a well-marked secondary maximum. The minimum mean temperature occurs with a N. wind. During the winter of 1932–33, however, winds from the SW. were the coldest and winds from the E. were the warmest.

6. NON-PERIODIC TEMPERATURE CHANGES.

When considering the non-periodic temperature variations occurring in any locality, it is customary to attempt to remove the true daily variation from the irregular changes, the residual variation being then assumed to be the true non-periodic variation.

In accordance with practice, therefore, the following table, which gives the reduced range of temperature from month to month, has been prepared from the mean of the two years' observations. The reduced range, which is the difference of the range and the amplitude of temperature, gives a qualitative measure of the non-periodic changes.

TABLE 14.—NON-PERIODIC TEMPERATURE CHANGES AT FORT RAE, 1882–83, 1932–33 COMBINED.

Month.	Mean Temperature.	Mean Maximum.	Mean Minimum.	Mean Range.	Amplitude.	Reduced Range.
	°C.	°C.	°C.	°C.	°C.	°C.
January . .	−31·89	−28·37	−35·05	6·68	2·53	4·15
February . .	−27·02	−21·65	−32·21	10·56	4·99	5·57
March . .	−20·83	−15·25	−27·03	11·78	8·25	3·53
April . .	−8·86	−3·78	−14·75	10·97	8·74	2·23
May . .	2·93	7·91	−2·23	10·14	6·94	3·20
June . .	10·79	15·11	6·40	8·71	6·34	2·37
July * . .	16·22	20·21	12·14	8·07	6·18	1·89
August * . .	15·24	19·16	11·41	7·75	6·15	1·60
September . .	7·03	11·26	3·45	7·81	5·33	2·48
October . .	−1·57	1·17	−4·20	5·37	2·52	2·85
November . .	−16·21	−12·61	−20·28	7·67	2·26	5·41
December . .	−25·54	−21·65	−29·50	7·85	1·39	6·46

* The values for July and August have been found from the formula: Mean $= \frac{1}{2}[82 + \frac{1}{2}(32 + 33)]$.

From the values of the reduced range it is seen that non-periodic temperature changes are largest in the winter months from November to February and smallest in the summer months July and August, the maximum being obtained in December and the minimum in August. The reduced range has almost the opposite yearly variation to the mean temperature, so that it may be stated that cold weather is favourable to unsteady temperatures while warm weather is unfavourable.

If we examine the mean temperature of the winter months still further, it is seen, however, that the mean temperature for January is the coldest, lower in fact than the mean temperature of the months on either side. The reduced range, however, is smaller in January than the reduced range for the months on either side, in spite of the fact that the mean temperature is lower. This characteristic is not only true for the results of the combined years, but for the two years separately, as the following table shows :—

TABLE 15.—MEAN TEMPERATURE AND REDUCED RANGES DURING THE WINTER.

Month.	Year.	Mean Temperature.	Reduced Range.	Year.	Mean Temperature.	Reduced Range.
		°C.	°C.		°C.	°C.
December . .	1882	−26·22	6·48	1932	−24·86	6·29
January . .	1883	−32·67	4·34	1933	−31·12	3·63
February . .	1883	−23·56	6·95	1933	−30·48	4·18

In order to find a possible explanation of this anomaly with the general results, it is of interest to quote from Simpson's discussion. He states that, "Every time a cold layer forms even for a few hours it is recorded by the minimum thermometer, but it must exist undisturbed throughout the 24 hours if it is to affect the maximum temperature. Similarly, a wind which only lasts a few minutes may raise the temperature and give a high maximum temperature, but if it does not last 24 hours it may not affect the minimum temperature.

"A month during which cold layers frequently form will have a low average minimum temperature. But the cold layer is very unstable, for at a comparatively small distance above it there is warm air; hence, during a period when the minimum temperature every day is low, there may be a large proportion of days with a relatively high maximum temperature. On the other hand, when windy conditions exist, both the maximum and minimum temperatures are high, for the cessation of the wind for a few minutes does not at once lead to a cold surface layer, which takes time to form. Thus, frequently when maximum temperatures are high, minimum temperatures are high, but much less frequently are maximum temperatures low when minimum temperatures are low. In other words, where the temperature is largely governed by the formation and removal of cold layers, average maximum temperatures cannot undergo such large variations as average minimum temperatures."

From the preceding statements we can expect maximum and minimum temperatures to be low together only when the cold layer is really stable, so that during these conditions, even in the winter, the range of temperature, and consequently the reduced range, tends to be small. If we can therefore show that during January the cold layer is more stable than during the months on either side, it would partially explain the smaller reduced range during the coldest month.

Upper air temperatures in the lowest layers of the atmosphere would be an asset, but only two were obtained, so that these are not sufficient to determine characteristics of the cold layer during the months under consideration. As a criterion of a more stable layer in January compared with the months on either side, we should expect at least three conditions to be satisfied: a lower temperature at the surface, a smaller mean wind velocity, and a greater percentage of calms. These three values for the individual years have been entered in Table 16.

TABLE 16.—SURFACE CONDITIONS DURING THE WINTER MONTHS.

Month.	Year.	Mean Temperature.	Mean Velocity.	Calms.	Year.	Mean Temperature.	Mean Velocity.	Calms.
		°C.	m/s.	%		°C.	m/s.	%
December .	1882	−26·22	1·5	32·9	1932	−24·86	3·90	32·0
January .	1883	−32·67	1·4	38·6	1933	−31·12	2·90	34·5
February .	1883	−23·56	2·4	25·1	1933	−30·48	4·68	21·8

The table shows that for both years January satisfies the three conditions which were stated would exist with a more stable layer of cold air near the surface.

In addition, if this is actually the case, then we should expect that the change of temperature from day to day would also be less during the month of January than during the months on either side. An examination of the interdiurnal change of temperature, both for rising and falling temperatures, has been carried out for the two years. The change of temperature from day to day has been calculated from the mean temperatures of the day, each mean being based upon 24-hourly values. Whenever the difference in the mean temperature was zero, the value has been entered both in the falling and rising temperatures, but it has been taken as a ½ count in each column. The results are entered in Table 17.

The table includes six columns which show the change of temperature from day to day during the two years, two during rising temperatures, two during falling temperatures, and two for changes irrespective of sign. In general, the values show similar results to those already obtained. The interdiurnal variability of temperature is greatest during the winter months and least during the summer months. But, in particular, five out of these six columns show a mean change of

TABLE 17.—INTERDIURNAL VARIABILITY OF THE MEAN DAILY TEMPERATURE.

Month and Year.	Temperature. Rising. Number of Days.	Temperature. Rising. Mean Change.	Temperature. Falling. Number of Days.	Temperature. Falling. Mean Change.	Mean Change Regardless of Sign.
		°C.		°C.	°C.
1882.					
September .	16	1·24	14	2·04	1·64
October . .	14½	1·36	16½	1·91	1·63
November .	12	4·25	19	3·61	3·93
December .	17	3·55	14	5·01	4·28
1883.					
January . .	17	2·90	14	3·31	3·11
February .	14	4·33	14	3·81	4·07
March . .	19	2·89	12	3·40	3·15
April . .	16	2·36	14	1·76	2·06
May . .	16	2·63	15	2·29	2·46
June . .	14½	2·38	15½	1·52	1·95
July . .	17	1·53	14	1·85	1·69
August . .	15	1·28	15	1·81	1·55

Month and Year.	Temperature. Rising. Number of Days.	Temperature. Rising. Mean Change.	Temperature. Falling. Number of Days.	Temperature. Falling. Mean Change.	Mean Change Regardless of Sign.
		°C.		°C.	°C.
1932.					
July . .	17	0·99	14	1·27	1·13
August . .	19½	1·27	11½	2·80	2·03
September .	18	1·06	12	2·17	1·61
October . .	17½	1·77	13½	3·47	2·62
November .	13½	3·70	16½	4·08	3·89
December .	19	2·95	12	4·75	3·85
1933.					
January . .	12½	3·53	18½	2·59	3·06
February .	18	2·81	10	3·50	3·15
March . .	14	4·40	17	3·44	3·92
April . .	16	2·86	14	2·28	2·57
May . .	20	1·69	11	2·54	2·11
June . .	16½	2·02	13½	1·67	1·85
July . .	20½	1·54	10½	2·54	2·04
August . .	14	1·23	16	1·48	1·35

temperature in the month of January less than the change of temperature for a month on either side. This, therefore, supports the previous evidence that during the month of January the cold layer of air is more stable than it is during the months on either side.

Consequently it may be said that non-periodic temperature changes are larger during the winter months than during the summer months, but that during the winter the changes are larger, with an unstable than with a stable cold layer near the surface.

Table 3, Vol. II, gives the absolute extremes of temperature for each day during the year 1932–33. The values have been determined from the maximum and minimum readings of the thermograph records of temperature and not from the maximum and minimum thermometers.

In Table 18 the monthly extremes of temperature for both years have been incorporated and the differences in the extremes for each month have been determined. It is noticed that the difference (highest maximum–lowest minimum) is greater during the winter months than during the summer months, both for the individual years and for the mean of the years. For the month of January, however, the difference is less than for the months on either side, a result which might be expected in view of the discussion in the preceding paragraphs.

TABLE 18.—MONTHLY EXTREMES OF TEMPERATURE.

Month		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
		°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
1882	Maxima.	..	..	..	..	..	..	..	..	20·4	12·7	1·4	− 4·7
1883	Maxima.	−15·6	− 3·5	− 8·3	7·4	18·5	24·7	24·7	25·6	..	..	..	..
1932	Maxima.	..	..	..	..	..	..	26·0	30·7	18·8	10·9	− 2·6	− 3·5
1933	Maxima.	−18·8	−16·7	− 1·4	6·2	15·9	25·7	24·2	26·9	..	..	..	..
1882	Minima.	..	..	..	..	..	..	..	..	− 3·7	−12·1	−35·7	−39·7
1883	Minima.	−44·6	−39·9	−39·9	−23·7	−17·9	− 2·3	8·7	3·3	..	..	..	..
1932	Minima.	..	..	..	..	..	..	9·4	4·3	− 1·2	−12·2	−36·1	−40·1
1933	Minima.	−42·2	−42·0	−36·9	−28·7	−14·2	− 1·3	7·1	6·2	..	..	..	..
1882	Difference (Max.–Min.).	..	..	..	..	..	..	..	..	24·1	24·8	37·1	35·0
1883	Difference (Max.–Min.).	29·0	36·4	31·6	31·1	36·4	27·0	16·0	22·3	..	..	..	..
1932	Difference (Max.–Min.).	..	..	..	..	..	..	16·6	26·4	20·0	23·1	33·5	36·6
1933	Difference (Max.–Min.).	23·4	25·3	35·5	34·9	30·1	27·0	17·1	20·7	..	..	..	..
Mean	Difference (Max.–Min.).	26·2	30·9	33·5	33·0	33·3	27·0	16·5*	22·9*	22·1	23·9	35·3	35·8

* Mean determined from formula: Mean $= \frac{1}{2}[83 + \frac{1}{2}(32 + 33)]$.

Tables 19, 20, 21 are statistical tables giving the number of days per month with mean, maximum and minimum temperatures between stated limits.

TABLE 19.—NUMBER OF DAYS PER MONTH WITH MEAN DAILY TEMPERATURES BETWEEN STATED LIMITS.

Month and Year.	Interval of Temperature in °C.													
	25·0 to 20·1	20·0 to 15·1	15·0 to 10·1	10·0 to 5·1	5·0 to 0·1	0·0 to −4·9	−5·0 to −9·9	−10·0 to −14·9	−15·0 to −19·9	−20·0 to −24·9	−25·0 to −29·9	−30·0 to −34·9	−35·0 to −39·9	⩽ −40·0
1932 July	7	18	6											
Aug.	11	15	2	3										
Sept.	..	..	4	22	4									
Oct.	..	..	..	1	4	13	12	1						
Nov.	..	..	..	..	..	1	4	5	4	8	5	3		
Dec.	..	..	..	..	..	..	1	2	3	8	10	4	3	
1933 Jan.	..	..	..	..	..	..	..	..	..	2	12	11	6	
Feb.	..	..	..	..	..	..	..	..	1	5	5	11	6	
Mar.	..	..	..	..	..	1	1	7	8	7	6	1		
Apr.	..	..	..	..	..	4	9	11	6					
May	..	..	1	10	17	3								
June	..	7	8	10	5									
July	..	17	14											
Aug.	3	17	11											
1882 Sept.	..	..	5	20	4	1								
Oct.	..	..	..	2	16	11	2							
Nov.	..	..	..	..	..	2	10	9	4	4	..	1		
Dec.	..	..	..	..	..	..	..	2	3	6	12	7	1	
1883 Jan.	..	..	..	..	..	..	..	..	1	2	8	9	6	5
Feb.	..	..	..	..	..	..	..	2	8	9	3	5	1	
Mar.	..	..	..	..	..	..	..	..	11	9	9	2		
Apr.	..	..	..	..	6	4	10	8	2					
May	..	..	2	9	11	5	2	2						
June	..	2	18	10										
July	..	23	8											
Aug.	..	10	17	4										

TABLE 20.—NUMBER OF DAYS PER MONTH WITH MAXIMUM TEMPERATURES BETWEEN STATED LIMITS.

Month and Year.	Interval of Temperature in °C.													
	30·0 to 25·1	25·0 to 20·1	20·0 to 15·1	15·0 to 10·1	10·0 to 5·1	5·0 to 0·1	0·0 to −4·9	−5·0 to −9·9	−10·0 to −14·9	−15·0 to −19·9	−20·0 to −24·9	−25·0 to −29·9	−30·0 to −34·9	−35·0 to −39·9
1932 July	2	16	13											
Aug.	10	12	4	2	2									
Sept.	..	..	2	14	13	1								
Oct.	..	..	..	1	2	6	15	7						
Nov.	..	..	..	..	..	..	3	4	5	6	7	4	1	
Dec.	..	..	..	..	..	..	1	4	..	7	10	4	4	1
1933 Jan.	..	..	..	..	..	..	..	..	..	1	6	14	6	4
Feb.	..	..	..	..	..	..	..	..	..	3	10	9	3	3
Mar.	..	..	..	..	..	..	1	7	8	9	4	2		
Apr.	..	..	..	..	1	..	12	11	6					
May	..	..	2	7	11	11								
June	1	4	8	10	5	2								
July	..	13	13	5										
Aug.	2	11	13	5										
1882 Sept.	..	1	5	18	4	2								
Oct.	..	..	..	3	8	16	2	2						
Nov.	..	..	..	..	..	3	7	10	6	3	..	1		
Dec.	..	..	..	..	..	..	1	1	4	3	10	8	4	
1883 Jan.	..	..	..	..	..	..	..	..	..	3	5	10	8	5
Feb.	..	..	..	..	..	..	1	4	3	8	8	3	1	
Mar.	..	..	..	..	..	..	..	2	13	9	6	1		
Apr.	..	..	..	..	1	13	8	6	2					
May	..	..	4	8	10	6	1	2						
June	..	3	14	10	3									
July	..	20	9	2										
Aug.	1	6	17	7										

TABLE 21.—NUMBER OF DAYS PER MONTH WITH MINIMUM TEMPERATURES BETWEEN STATED LIMITS.

Month and Year.	Interval of Temperature in °C.												
	20·0 to 15·1	15·0 to 10·1	10·0 to 5·1	5·0 to 0·1	0·0 to −4·9	−5·0 to −9·9	−10·0 to −14·9	−15·0 to −19·9	−20·0 to −24·9	−25·0 to −29·9	−30·0 to −34·9	−35·0 to −39·9	⩽ −40·0
1932 July	10	19	2										
Aug.	12	15	2	2									
Sept.	..	..	7	21	2								
Oct.	..	..	..	4	6	13	8						
Nov.	..	..	..	..	..	2	3	6	4	5	9	1	
Dec.	..	..	..	..	..	1	..	3	8	9	3	5	2
1933 Jan.	..	..	..	..	..	..	..	..	1	5	11	12	2
Feb.	..	..	..	..	..	..	..	..	2	4	4	13	5
Mar.	..	..	..	..	..	..	2	3	10	6	7	3	
Apr.	..	..	..	..	..	5	6	11	6	2			
May	..	..	1	13	13	3	1						
June	..	9	10	9	2								
July	1	20	10										
Aug.	5	20	6										
1882 Sept.	..	..	9	17	4								
Oct.	..	..	..	7	19	4	1						
Nov.	..	..	..	..	..	4	8	10	3	4	..	1	
Dec.	..	..	..	..	..	..	..	2	2	7	12	8	
1883 Jan.	..	..	..	..	..	..	..	..	2	4	6	11	8
Feb.	..	..	..	..	..	..	..	..	9	7	6	6	
Mar.	..	..	..	..	..	..	..	1	6	12	8	4	
Apr.	..	..	..	..	7	3	6	8	6				
May	..	..	..	11	11	3	4	2					
June	..	3	15	11	1								
July	3	22	6										
Aug.	2	12	14	3									

PART II.—PRESSURE

1. INSTRUMENTS AND METHODS

(a) *Barometers.*—Two Kew pattern barometers, the standard No. M.O. 1725/28 and the subsidiary No. M.O. 1692, were taken by the expedition to Fort Rae and were erected on the N.E. wall of the main station adjacent to one another, their cisterns being at the same level. Full details of these barometers are to be obtained in the *Observer's Handbook* of the Meteorological Office, London.

In addition, a Fortin barometer, which had been loaned by the Canadian Meteorological Office and which had been taken to Fort Rae the previous year, was also erected by the side of the two Kew pattern barometers. Unfortunately, this barometer has, since its return, been destroyed by fire, and its certificate is no longer available.

During the month of July 1932 these three barometers were read against one another at the observational hours, and from the readings then taken the values agreed within 0·1 mb., showing that no leak had developed in the barometers. During August 1932 the two Kew pattern barometers were read against one another three times per day, at 8h, 14h, and 20h, and for the rest of the year until the end of August 1933 this intercomparison continued four times per day, at 2h, 8h, 14h, and 20h. After correcting the readings for index error, temperature, and latitude, the mean differences between the standard No. M.O. 1725/28 and the subsidiary No. M.O. 1692 for months equally distributed throughout the year are as given in the following table :—

TABLE 22.—MEAN DIFFERENCES OF PRESSURE (STANDARD–SUBSIDIARY), 1932–33, AT STATION LEVEL.

	August 1932.	November 1932.	February 1933.	May 1933.	August 1933.
Difference (mb.) .	−0·07	−0·11	−0·13	−0·09	−0·08
No. of observations . .	93	120	112	124	123

The mean value for these five equally distributed months shows that the subsidiary barometer read 0·1 mb. above that of the standard barometer throughout the year, and the constancy of the mean differences shows that this was maintained during the year.

Both the barometers had N.P.L. certificates, but neither barometer was re-tested on its return to England. Indeed, if any error was determined, it would be difficult to say whether the error had occurred prior to leaving Fort Rae or during its transit to England. The constant comparison and agreement which occurred during the whole year is a sufficient check that nothing had happened to the barometers, for it is difficult to imagine that a leak had occurred which affected the two barometers equally. In addition, there was the third independent Fortin barometer, which also checked the observations during the early period and whose difference from the standard was not greater than ±0·1 mb. Owing to the loss of the certificate, the mean differences between the Fortin and the standard cannot be given.

Table 4, Vol. II, based upon the N.P.L. certificate of the standard barometer, gives the corrections applied to the pressure readings in order to correct for index error, temperature, and latitude. These corrections were applied throughout the year to reduce the observed readings of the standard to correct readings at station level. Full details upon the method of obtaining the values in the correction table are also given in the *Observer's Handbook* of the Meteorological Office, London, 1934.

The height of the barometer cistern above the level of the lake was 19 ft. 1 in. The level of the lake, supplied by courtesy of the Topographical Survey Department of the Interior, Ottawa, is at a height of 520±5 ft.

(b) *Method of reduction of observations.*—Two barographs were in use at Fort Rae during the period of the expedition. One was a medium weekly barograph of the standard pattern as used at some of the British meteorological stations. This barograph was taken as the standard throughout the year. The other was an open scale daily barograph also of standard pattern.

From 1932 August 1 to 1933 August 31 readings of the barometer were taken every three hours, at the exact hours, commencing at 2h. Immediately after the 8h observation the pen of the standard barograph was depressed, so that on each weekly chart there were six time marks in addition to the beginning and end of the record whose times and corresponding pressures were known. In addition, there were 48 other control pressures at known times. The control pressures were all corrected for temperature, index error, and gravity.

By means of the time marks and a celluloid scale divided into hourly intervals fitting the chart, the curve could be read at the exact hours. The clock kept exceedingly good time throughout the year, and even when the rate of the clock changed it was easy to mark the curve by a series of dots corresponding to the exact hours. Two independent sets of readings were taken, no pair of readings being allowed to pass if they differed by more than 0·2 mb. If such a difference occurred, an independent set of readings was taken. The differences between the 56 corrected control pressures and the corresponding curve readings were plotted on squared paper and a difference curve was drawn through the points. In this way a few incorrect pressure readings were noted and omitted. The difference curve was read off every hour and the value entered against the corresponding value from the barograph curve. The barograph value and the difference value were then added at every hour, giving the correct barometer reading.

By this method it is believed that the hourly values of pressure are correct to ±0·3 mb.

(c) *The pressure observations of* 1882–83.—As far as possible, use has been made of the results of the first expedition to Old Fort Rae in 1882–83 in order that the data may cover a longer period. But it must be mentioned that there is an indeterminancy in regard to the pressure observations as published for that year.

In order to obtain readings at station level it is customary when correcting the eye observations of a Kew pattern barometer to correct for index error, temperature, and latitude, but there is no reference in the results of the first expedition to the fact that index error or temperature corrections have been applied. Furthermore, in accordance with the resolution passed at the Fourth International Polar Conference at Vienna in April 1884, which states, "Es ist obligatorisch, die Luftdruckangaben ohne Correction für die Schwere zu veröffentlichen, gleichzeitig aber die Grösse dieser Correction mit zugehörigen Luftdruckwerth auf jeder Seite der Tabellen ersichtlich zu machen," a gravity correction of +1·17 mm. at 754 mm. has been given, but no such correction has been applied to the observations. This correction amounts to +1·56 mb. at 1005 mb., but the magnitude of the correction varies with the pressure, so that in order to make the hourly values of the 1882–83 expedition strictly comparable with those of 1932–33, a gravity correction depending upon the pressure at the time should be applied to all the hourly readings.

If reference be made to the *Observer's Handbook*, 1934, it will be seen that the gravity correction now applied to a Kew pattern barometer at Old Fort Rae, latitude 62° 38′ 50″ N., amounts to +1·51 mb. at 1005 mb., which differs slightly from the value +1·56 mb. at 1005 mb. given in the results of the first expedition.

Owing to these uncertainties in regard to corrections for index error, temperature, and gravity in the results of the first expedition, it has been decided that the values as published be used in the following discussion, but the mm. of mercury have been converted into mb. according to the formula:—

$$1000 \text{ mb.} = 750{\cdot}076 \text{ mm.}$$

2. ANNUAL VARIATION OF PRESSURE

The following table contains the monthly mean values of pressure at Fort Rae and Old Fort Rae for the two years:—

TABLE 23.—MONTHLY MEAN VALUES OF THE BAROMETRIC PRESSURE AT STATION LEVEL.
900 mb. + Tabulated Value.

Place.	Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
		mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
Old Fort Rae .	1882	..	..	..	..	..	..	..	..	91·70	87·95	91·07	96·06
	1883	101·74	99·59	101·92	93·20	95·85	89·20	90·28	90·54	..	..	..	..
Fort Rae . .	1932	..	..	..	..	..	..	..	88·13	89·94	94·78	97·36	95·36
	1933	92·29	100·63	99·67	99·67	93·98	91·26	91·35	91·19	..	..	..	..
Mean (direct) . .		97·01	100·11	100·79	96·43	94·91	90·23	90·81	90·10*	90·82	91·37	94·21	95·71

* The direct mean for the three August months has been determined according to the formula:

$$\text{Mean} = \tfrac{1}{2}[83 + \tfrac{1}{2}(32 + 33)].$$

The above values have been plotted in fig. 6 and the months of the respective years have been joined by a characteristic line. The direct means for the two years have also been plotted and are represented by the thick line in the figure. The combined observations give a fairly smooth curve even for two years' observations.

Considering the curve for 1882–83, the maximum pressure occurs in March and the minimum in October. In particular, the pressure remains high during the cold months from January to March and low in the warmer months from June to October, thereafter rising steadily to its winter maximum. This is characteristic of the continental type of annual pressure variation, which has a maximum in the winter and a minimum in the summer. Barnaul,* in West Siberia, 53° 20′ N., 83° 47′ E., has a maximum mean pressure of 1008·4 mb. in January and a minimum mean pressure of 986·5 mb. in July, with a variation during the year of 21·9 mb. compared with a variation of 14·0 mb. during the year 1882–83 at Old Fort Rae.

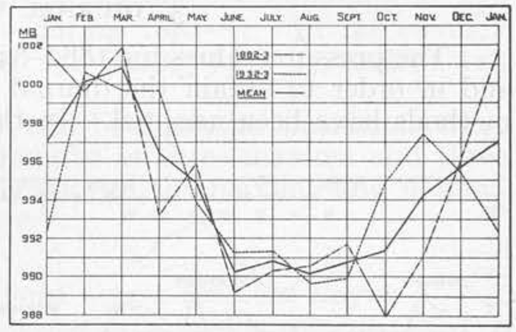


FIG. 6.—Annual variation of the barometric pressure.

The curve for the year 1932–33 differs from that of the year 1882–83 in showing a secondary maximum of pressure in November. The pressure remains high during the late winter and early spring months from February to April, and it attains its lowest values during the months August to September, but it shows a secondary maximum in November and a secondary minimum in January. This type of annual variation of pressure has been classified by Hann as belonging to the arctic or sub-arctic type of annual variation. The following table gives the variation of the mean monthly pressure from the mean of the year for other localities showing a similar annual variation:—

TABLE 24.—VARIATION OF MEAN MONTHLY PRESSURE FROM THE MEAN OF THE YEAR IN MB. (HANN).

Locality.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
North Greenland, 80° N. .	−3·1	−1·6	1·3	8·5	5·6	−2·7	−4·4	−2·7	−3·7	0·0	3·2	−0·8
Arctic North America, 77° N.	−3·5	−0·1	2·7	6·9	4·8	−0·8	−4·7	−3·6	−3·6	0·1	2·8	−1·1
Fort Rae, 63° N. . .	−2·4	5·9	5·0	5·0	−0·7	−3·4	−3·4	−5·0	−4·8	0·1	2·7	0·7

In the three localities given in the table the secondary maximum occurs in November, but the principal maximum at the more northerly latitudes occurs in the month of April, whereas at Fort Rae, farther south, it is advanced to the month of February.

The curve obtained from the direct means of the two years, however, is fairly smooth and in its main features is probably correct. It shows an annual variation with a maximum pressure during the late winter and early spring months, after which the pressure falls steadily to a minimum in the summer, remaining fairly uniform from June to October and then rising to its maximum in February or March.

The harmonic analysis of the direct means for the combined years gives the following expression for the annual variation:—

$$\dagger\ \Delta P = 4{\cdot}9 \sin(30t + 40{\cdot}9) + 1{\cdot}05 \sin(60t + 308{\cdot}8) + 0{\cdot}52 \sin(90t + 216{\cdot}4),$$

where t is the time in months reckoned from 0h. January 1.

* Hann, *Lehrbuch der Meteorologie*, pp. 198–199.

† This formula is based on the assumption that the months are of equal length and that the mean value for the month is appropriate to the midpoint of the month. The errors arising from these assumptions are discussed in a paper entitled, "The Use of Monthly Mean Values in Climatological Analysis," by E. G. Bilham in *Quart. J. R. Met. Soc.*, vol. xliv, p. 41 (1918). To obtain the January value from the formula we put $t = \frac{1}{2}$, to obtain the February value we put $t = 1\frac{1}{2}$, etc.

The analysis reveals no new feature except that the ratio of the amplitude of the semi-annual wave to the amplitude of the annual wave is 0·21, so that the second term has an appreciable effect upon the course of the annual variation. The annual wave attains its maximum on the 49·8 day of the year.

3. DIURNAL VARIATION OF PRESSURE

The pressure values for 1882–83 have been published in millimetres of mercury, and in order to obtain the diurnal inequalities in millibars from these values two methods have been adopted. In the first method the departures in millimetres of

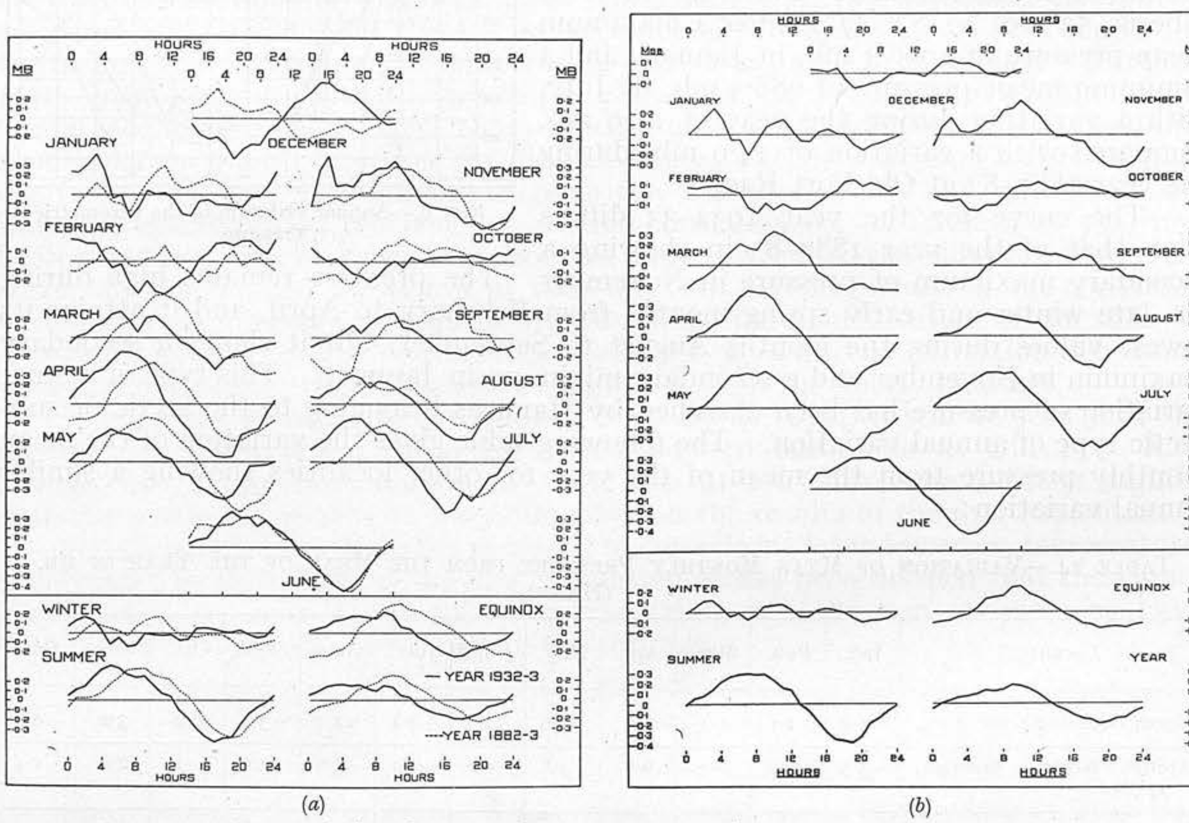


FIG. 7.—(*a*) Diurnal variation of pressure for the individual years; (*b*) Diurnal variation of pressure for the combined years.

mercury from the mean monthly pressure were converted into departures expressed in millibars by multiplication with the factor 1·33. The non-cyclic correction was then added, giving the inequalities in mb. In the second method the departures and the non-cyclic correction were expressed in mm. of mercury, and the resulting inequalities were expressed in mb. by multiplication with the factor 1·33. The two methods give practically identical results except at occasional hours, where the difference amounted in the maximum to 0·01 mb. Consequently, the inequalities obtained by the first method have been adopted as the diurnal inequalities for the year 1882–83.

It should again be stated that the times used during the two expeditions were different; but that, owing to the small time difference and to the fact that the diurnal inequality of pressure is a slowly changing variable, it has been considered that the combination of the inequalities for 1882–83 at the exact hours of local mean time with the inequalities for 1932–33 at the exact hours of zonal mean time will only affect the validity of such a combination very slightly. Consequently, for the combined years this method has been adopted.

(a) *The diurnal inequalities.*—The inequalities for the individual years and the combined years, carried out according to the above procedure, have been entered in Table 5, Vol. II, and the inequalities have been plotted in fig. 7 (*a*), (*b*), in such a way that the months having similar solar conditions are brought into juxtaposition.

All the months from March to September in the individual years show a morning maximum and an afternoon or evening minimum, except the month of September 1882, which shows a morning minimum at 4h and an evening maximum at 17–18h. On the mean of the summer the maximum occurs at 5h and the minimum at 17h during 1932–33, and at 9h and 19h respectively during 1882–83. In the equinox the maximum occurs at 9h and the minimum at 17h during 1932–33, and at 11h and 24h during 1882–83.

If the individual months December, January, and February be considered, there is more or less evidence in five out of the six months of three maxima and three minima. The following table gives the characteristics of the maxima and minima occurring during these months:—

TABLE 25.—CHARACTERISTICS OF MAXIMA AND MINIMA DURING THE COLD MONTHS.

Date.	Times of Occurrence in Hours from Midnight of					
	1st Max.	2nd Max.	3rd Max.	1st Min.	2nd Min.	3rd Min.
Jan. 1933 . .	3	9	16	7	14	20
Jan. 1883 . .	3	11	16	7	13	24
Feb. 1933 . .	0	9*	20–21	8	11	23
Feb. 1883 . .	5	11	19	7–8	15	24
Dec. 1882 . .	3	9	18*	6–7	13	20
Winter 1932–33 .	2	9	16	7	13	22
Winter 1882–83 .	3	11	18	7	15	20
Combined Winter .	3	11	16	7	14	20
	Deviations of Maxima and Minima from the Mean Pressure.					
	mb.	mb.	mb.	mb.	mb.	mb.
Jan. 1933 . .	0·43	0·04	−0·06	−0·25	−0·23	−0·13
Jan. 1883 . .	0·11	0·30	0·16	−0·18	0·06	−0·25
Feb. 1933 . .	0·23	−0·20	0·21	−0·34	−0·35	−0·08
Feb. 1883 . .	0·15	0·16	0·11	−0·04	−0·21	−0·10
Dec. 1882 . .	0·32	0·13	−0·06	0·08	−0·24	−0·16
Winter 1932–33 .	0·175	−0·005	0·060	−0·135	−0·073	−0·045
Winter 1882–83 .	0·100	0·173	−0·007	−0·030	−0·035	−0·170
Combined Winter .	0·113	0·078	0·027	−0·083	−0·041	−0·097

* A weak maximum.

The month of December 1932 shows no evidence of these three maxima. The early morning and noon maxima are also in evidence for the month of November 1932.

The three maxima and minima are well represented in the curve for the individual winters as well as the winter for the combined years, and their characteristics are also entered in the preceding table. It is still doubtful, owing to the few years under consideration, whether this is a general feature of the pressure inequalities during the winter months.

The amplitudes of the diurnal variation in the different months of the year are given in Table 26.

The maximum amplitude occurs in a spring month, the minimum in a late autumn or winter month.

Further discussion of the diurnal inequalities can best be continued by reference to the harmonic analysis of the inequalities.

TABLE 26.—AMPLITUDE OF THE DIURNAL VARIATION OF PRESSURE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
1882	..	..	..	..	..	..	..	..	0·75	0·47	0·65	0·56
1883	0·55	**0·37**	0·84	0·82	**09·8**	0·79	0·77	0·48	..	..	...	..
1932	..	..	..	..	..	..	..	0·66	0·45	**0·36**	0·75	0·80
1933	0·68	0·58	0·61	**1·10**	0·74	0·84	0·98	0·68	..	..	..	..
Combined Yrs.	0·48	0·33	0·56	**0·91**	0·77	0·76	0·73	0·52	0·40	0·29	0·66	**0·25**
Arith. Mean	0·61	0·47	0·73	**0·96**	0·86	0·81	0·87	0·57	0·60	**0·41**	0·70	0·68

(b) *The harmonic coefficients.*—The harmonic coefficients of the diurnal inequalities of pressure for the years 1932–33, 1882–83, and for the combined years are given in Table 27.

(c) *The 24-hourly wave. Amplitude.*—The arithmetic mean annual values of the amplitudes of the 24-hourly period for both years were nearly identical, namely, 0·27 mb. for 1882–83 and 0·29 mb. for 1932–33, but the values for the corresponding months in the two years vary considerably. For Old Fort Rae the values show that the maximum amplitudes occurred during the spring and early summer months from March to June, and for Fort Rae they occurred from April to July. The values for the combined years give a more uniform change in the amplitudes from month to month, showing a maximum amplitude in April and a minimum in January, with a range of 0·36 mb. for the year. The annual variations of the amplitude for the years are expressed by the formulæ :—

1882–83 . . $c_1 = 0{\cdot}270 + 0{\cdot}111 \sin (30t + 297{\cdot}5) + 0{\cdot}085 \sin (60t + 204{\cdot}5) + 0{\cdot}026 \sin (90t + 159{\cdot}5)$

1932–33 . . $c_1 = 0{\cdot}290 + 0{\cdot}095 \sin (30t + 313{\cdot}3) + 0{\cdot}050 \sin (60t + 129{\cdot}4) + 0{\cdot}089 \sin (90t + 169{\cdot}6)$

Combined years $c_1 = 0{\cdot}228 + 0{\cdot}145 \sin (30t + 298{\cdot}3) + 0{\cdot}053 \sin (60t + 199{\cdot}0) + 0{\cdot}052 \sin (90t + 204{\cdot}6)$

where t is the time in months reckoned from 0h. on January 1. The magnitudes of the amplitudes in the three components of these Fourier series are of the same order, so that a further extension of the series would be necessary for a good representation of the annual variation. The convergence of the series is slow, as is seen in particular from the representation of the variation for 1932–33 where the amplitude of the third Fourier component is practically equal to that of the first.

Phase.—The phase of the 24-hourly wave is not constant throughout the year, but it shows its most constant values in the months March to September for the year 1932–33, and from March to August in the year 1882–83. This agrees with what has already been stated concerning the regularity of the morning maximum and the evening minimum occurring in these months. During these months the phase for 1932–33 is generally larger than the phase for 1882–83, again agreeing with the fact that the maximum during 1932–33 is advanced on the maximum of 1882–83.

For the remaining months the phases will depend mainly upon whether the morning, noon, or evening maximum is well developed, and as these maxima are well developed at different times from month to month, so also will the phase of the 24-hourly wave vary from month to month. This is seen to be the case in the harmonic analysis.

(d) *12-hourly wave.*—Simpson * has shown that the observed amplitude and phase of the mean annual 12-hourly barometer oscillation in all parts of the world can be explained by the existence of two atmospheric vibrations, one around the world, travelling from E. to W. parallel to the circles of latitude, and the other a vibration between the equator and the poles parallel to the circles of longitude.

* G. C. Simpson, *Quart. J. R. Met. Soc.*, vol. xliv, pp. 1–18 (1918).

TABLE 27.—HARMONIC COEFFICIENTS OF THE DIURNAL INEQUALITIES OF PRESSURE—OLD FORT RAE. Longitude 115° 48′ 41″ W.
" " " " " " " —FORT RAE. Longitude 116° 4′ 3″ W.

Values of c_n, α_n in the series $\Sigma c_n \sin(15nt+\alpha_n)$, t being local apparent time in hours from midnight.

Month and Season.	Old Fort Rae.									Fort Rae.								Combined Years.							
	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.		c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
	mb.	°	mb.	°	mb.	°	mb.	°		mb.	°	mb.	°	mb.	°	mb.	°	mb.	°	mb.	°	mb.	°	mb.	°
January 1883	·15	275	·07	19	·10	358	·07	222	1933	·17	57	·11	44	·10	351	·06	215	·05	357	·08	30	·10	347	·07	211
February "	·05	13	·05	215	·08	293	·05	160	"	·26	120	·09	325	·03	14	·01	293	·13	110	·04	291	·04	303	·02	154
March "	·39	293	·05	144	·05	266	·01	32	"	·23	351	·03	152	·04	257	·02	169	·27	311	·04	142	·04	256	·03	142
April "	·38	312	·08	123	·05	135	·01	30	"	·52	359	·05	179	·03	104	·03	315	·41	338	·05	138	·04	116	·02	327
May "	·46	319	·05	67	·02	101	·01	129	"	·31	1	·04	143	·05	196	·03	217	·36	334	·03	62	·02	173	·02	195
June "	·36	1	·09	92	·04	116	·02	324	"	·35	355	·05	101	·04	183	·03	176	·36	356	·07	90	·03	138	·01	209
July "	·33	326	·07	109	·04	113	·01	0	"	·44	10	·03	159	·03	256	·02	80	·35	350	·05	115	·01	138	·01	47
August "	·17	325	·07	137	·05	180	·02	88	"	·29	27	·07	111	·03	218	·03	204	·22	345	·06	119	·04	189	·01	124
August									1932	·30	358	·04	109	·04	225	·01	124								
September 1882	·31	229	·06	215	·05	69	·02	138	"	·18	326	·05	154	·02	298	·02	252	·17	256	·05	156	·03	41	·01	170
October "	·19	249	·04	156	·05	14	·01	244	"	·10	149	·06	62	·02	344	·01	160	·10	218	·04	92	·03	49	·01	180
November "	·26	289	·07	35	·06	17	·02	126	"	·30	337	·05	51	·11	356	·03	311	·25	313	·06	38	·09	359	·01	326
December "	·19	31	·02	324	·07	20	·04	215	"	·33	196	·05	22	·01	0	·01	276	·07	183	·03	4	·04	7	·02	216
Winter . .	·114	318	·023	18	·065	357	·036	191		·047	107	·058	19	·062	359	·018	254								
Summer . .	·313	333	·042	83	·032	135	·032	6		·349	3	·040	123	·032	209	·018	185								
Equinox . .	·270	276	·044	156	·016	75	·004	114		·205	352	·034	137	·009	287	·009	244								
Year . .	·207	309	·031	111	·017	36	·010	177		·180	3	·025	84	·015	324	·012	225	·169	332	·027	86	·014	354	·010	196
Arithmetic Mean	·270	..	·060	..	·055	..	·024	..		·290	..	·060	..	·043	..	·026	..	·228	..	·050	..	·043	..	·020	..

The empirical formulæ, which express the amplitude and the phase of the mean annual semi-diurnal oscillation, are given below.

$$\text{Amplitude (mb.)} = [\{1{\cdot}249 \cos^3\phi \sin 154^\circ + 0{\cdot}183 (\sin^2\phi - \tfrac{1}{3}) \sin (105^\circ - 2\lambda)\}^2 + \{1{\cdot}249 \cos^3\phi \cos 154^\circ + 0{\cdot}183 (\sin^2\phi - \tfrac{1}{3}) \cos (105^\circ - 2\lambda)\}^2]^{\frac{1}{2}}$$

$$\tan A = \frac{1{\cdot}249 \cos^3\phi \sin 154^\circ + 0{\cdot}183 (\sin^2\phi - \frac{1}{3}) \sin (105^\circ - 2\lambda)}{1{\cdot}249 \cos^3\phi \cos 154^\circ + 0{\cdot}183 (\sin^2\phi - \frac{1}{3}) \cos (105^\circ - 2\lambda)},$$

where ϕ and λ represent the latitude and longitude of the station, the latter being reckoned positive to the E. and negative towards the W.

The amplitude and the phase of the semi-diurnal oscillation have been calculated according to the above formulæ for the two stations, Old Fort Rae and Fort Rae, and the results have been compared with the observed values. The details of the comparison are entered in Table 28.

TABLE 28.—THE 12-HOURLY BAROMETER OSCILLATION AT
OLD FORT RAE. Lat. 62° 38′ 50″ N. Long. 115° 48′ 41″ W.
FORT RAE. Lat. 62° 49′ 46″ N. Long. 116° 4′ 3″ W.

Station.	Year.	c_2.		a_2.		$\frac{c_2 \text{ computed}}{c_2 \text{ observed}}$	a_2 computed — a_2 observed.
		Computed.	Observed.	Computed.	Observed.		
		mb.	mb.	°	°		°
Old Fort Rae	1882–83	0·038	0·031	148	111	1·23	37
Fort Rae .	1932–33	0·034	0·025	147	84	1·36	63

Considering the smallness of the amplitudes, there is a fairly good agreement between the observed and the computed values, the agreement being closer during 1882–83 than during 1932–33.

The phases do not show quite as good an agreement with the computed values, the difference between the computed and the observed values being greater in 1932–33 than in 1882–83. The time difference between the computed and the observed values amounts to about one hour in 1882–83 and about two hours in 1932–33.

Simpson has previously compared the values for Old Fort Rae with the computed values and he states: "Take the case of Fort Rae in latitude 62° 39′ N., longitude 115° 44′ W., the theoretical values for which are amplitude 0·028 mm. . . . and phase 148°. A single year's observations by the British Expedition under Captain H. P. Dawson, R.A., in 1882–83, found the amplitude to be 0·026 mm. and phase 115°, which shows not only good agreement with theory, but also indicates good observing." From this it is seen that the theoretical value is thus 0·037 mb. and 148°, whereas the observed value is 0·035 mb. and 115°.

A comparison of these values with those given in Table 28 for Old Fort Rae shows that the two theoretical values differ by 0·001 mb. in the amplitude. This arises from the fact that the longitude found for Old Fort Rae during more recent observations differs slightly from that determined by Dawson and used by Simpson. They also show a slight difference in the observed values for Old Fort Rae, amounting to 0·004 mb. in amplitude and 4° in phase. These amounts are very small and in all probability arise from the manner in which the inequalities are determined and their conversion into mb. The degree of indeterminancy attached to the pressure values themselves as published for 1882–83 makes these small differences unimportant.

4. NON-PERIODIC PRESSURE CHANGES

(a) Table 29 contains characteristics of non-periodic pressure changes at Fort Rae and Old Fort Rae based upon two years' observations.

The highest recorded pressure is 1035·4 mb. and the lowest 961·8 mb., the difference being 73·6 mb. The month with the greatest absolute range is December with 63·2 mb., and the month with the least range is July with 30·7 mb.

The mean difference between the daily maximum and the daily minimum pressure is greater during the winter months than during the summer months, the maximum value being 9·5 mb. in February and the minimum value being 4·1 mb. in July.

TABLE 29.—CHARACTERISTICS OF NON-PERIODIC PRESSURE CHANGES FOR TWO YEARS, 1882–83, 1932–33.

Month.	Absolute Value in 2 Years.			Average Difference between Highest and Lowest in each Month of 2 Years.	Mean Difference between Daily Maximum and Minimum.	Highest Monthly Mean in 2 Years.	Lowest Monthly Mean in 2 Years.	Difference between Highest and Lowest Monthly Mean.
	Highest.	Lowest.	Difference.					
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
January	1027·5	973·6	53·9	44·4	7·6	1001·7	992·3	9·4
February	1035·4	979·8	55·6	51·9	9·5	1000·6	999·6	1·0
March	1025·4	974·3	51·1	49·9	8·1	1001·9	999·7	2·2
April	1017·1	974·3	42·8	38·2	6·7	999·7	993·2	6·5
May	1010·8	972·1	38·7	34·9	4·9	995·9	994·0	1·9
June	1007·2	973·0	34·2	30·3	5·3	991·3	989·2	2·1
July	1004·1	973·4	30·7	25·9	4·1	991·3	990·3	1·0
August *	1005·5	969·3	36·2	31·7	4·8	991·2	988·1	3·1
September	1015·0	964·3	50·7	44·4	7·5	991·7	989·9	1·8
October	1016·6	965·0	51·6	42·7	7·2	994·8	987·9	6·9
November	1017·1	961·8	55·3	48·5	9·1	997·4	991·1	6·3
December	1027·6	964·4	63·2	59·5	9·1	996·1	995·4	0·7

* August is based on the three Augusts, 1932, 1933, and 1883.

The mean monthly values of the interdiurnal variability of pressure have also been determined by forming mean values, regardless of sign, of the differences in the mean daily pressure on consecutive days. The results are entered in Table 30.

TABLE 30.—INTERDIURNAL VARIABILITY OF PRESSURE

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
1882	..	..	..	..	..	..	..	..	5·69	4·37	7·04	7·30
1883	6·61	5·34	6·53	6·07	4·18	4·26	2·94	4·06	..	..	..	..
1932	..	..	..	..	..	..	..	3·78	5·96	6·45	6·17	6·21
1933	5·40	7·30	4·99	4·60	3·47	4·58	3·27	4·14	..	..	..	..
Mean	6·01	6·32	5·76	5·33	3·83	4·42	3·11	4·01*	5·83	5·41	6·61	6·75

* Mean $= \frac{1}{2}[83 + \frac{1}{2}(32 + 33)]$.

They show that the interdiurnal variability is greatest in the winter months and least in the summer months, the highest value being 7·30 mb. in December 1882 and in February 1933, and the lowest being 2·94 mb. in July 1883.

TABLE 31.—GREATEST CHANGE IN MEAN DAILY PRESSURE IN 24 HOURS.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
1882	..	..	..	..	..	..	..	..	12·53	15·61	19·81	21·12
1883	20·83	16·64	15·37	20·45	12·67	13·61	7·99	9·45	..	..	..	..
1932	..	..	..	..	..	..	..	9·00	15·20	16·90	20·20	16·10
1933	20·50	21·20	16·50	18·00	12·90	12·70	12·00	11·60	..	..	..	..

Based on the observations of two years, the mean values show the maximum 6·75 mb. occurring in December, and the minimum 3·11 mb. occurring in July.

In Table 31 has been entered the greatest change in the mean daily pressure which occurred in 24 hours. The values do not show such a good regularity as the inter-diurnal variability of pressure, but they do show that the greatest changes in the mean daily pressure occur in the winter months and the least in the summer months.

(b) *Maxima and minima of pressure*, 1932–33.—Table 6, Vol. II, shows the maxima and minima of pressure for each day of the year at station level as obtained from the hourly values of pressure.

The highest value recorded was 1035·4 mb. at 10h and 11h February 7, 1933, which is also the highest value recorded in two years' observations. The lowest recorded value was 964·3 mb. at 18h to 20h September 13, 1932, with another value equally as low of 964·4 mb. at 3h December 23, 1933. The lowest value recorded in two years' observations is 961·8 mb. at 2h to 3h November, 13 1882, at Old Fort Rae.

The annual variations of the mean monthly maximum and minimum of pressure based on the two years' observations have been entered in Table 32 below.

TABLE 32.—ANNUAL VARIATION OF THE MEAN MONTHLY MAXIMUM AND MINIMUM OF PRESSURE, 1932–33, 1882–83.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.*	Sept.	Oct.	Nov.	Dec.
mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
Maxima.											
000·8	004·9	004·9	999·7	997·4	992·9	992·9	992·5	994·5	995·0	998·5	000·3
Minima.											
993·2	995·4	996·7	993·1	992·5	987·7	988·8	987·7	986·9	987·7	989·5	991·2

* Results are based upon three August months.

The annual variations consist of single periods with maxima in the late winter or early spring and minima in the summer months.

5. PRESSURE WAVES

It is customary when considering the variation of pressure with time to determine the lengths and periods of pressure "waves," which have usually been defined as those "waves" for which the difference between the maximum and the following minimum and the difference between this minimum and the following maximum were both greater than 5 mm. The data which we shall consider have been given in mm. of mercury for 1882–83 and in mb. for 1932–33, and as 5 mm. is equal to 6·67 mb., this has been taken as a corresponding limit for the data of 1932–33.

All the hourly values for the two years have been examined and all the successive maxima and minima have been noted. The results for the two years' observations are contained in the following table:—

TABLE 33.—PRESSURE WAVES AT OLD FORT RAE AND FORT RAE.

Year.	Period.		Amplitude.
	Hours.	Days.	mb.
1882–83	150·4	6·3	21·7
1932–33*	132·8	5·5	18·7
2 years	140·7	5·9	20·0

* The year consists of 13 months.

The waves were also classified according to the seasons of the year, with the following results:—

TABLE 34.—PRESSURE WAVES DURING THE DIFFERENT SEASONS.

Year.	Period in Hours.				Amplitude in mb.			
	Spring.	Summer.	Autumn.	Winter.	Spring.	Summer.	Autumn.	Winter.
1882–83	154·6	167·5	172·9	127·3	25·0	16·5	21·1	24·5
1932–33	108·0	225·4	90·8	110·8	16·7	19·0	17·8	20·3
Mean	131·3	196·5	131·9	119·1	20·9	17·7	19·5	22·4

It is seen from Table 34 that the period is the longest in the summer and the shortest in the winter, but that the amplitude is the greatest in the winter and the least in the summer. Consequently, the mean hourly change is much greater in winter than in summer. The following table gives the mean hourly change which occurred during the various seasons:—

TABLE 35.—MEAN HOURLY CHANGE IN MILLIBARS PER HOUR.

Year.	Spring.	Summer.	Autumn.	Winter.	Year.
1882–83	0·32	0·20	0·24	0·38	0·29
1932–33	0·31	0·17	0·39	0·37	0·28
Mean	0·31	0·19	0·31	0·37	0·29

The agreement for the corresponding seasons of the different years is comparatively good.

The data have also been examined in order to determine the number of pressure waves whose periods lie within certain specified ranges. Table 36 gives the results of the analysis together with the amplitudes of these waves of different periods.

A further analysis has been made to determine whether or not certain periods exist with a greater frequency than others, and for this purpose all waves during the two years whose periods lie between the intervals 1 to 5, 6 to 10, 11 to 15, etc. hours have been noted, and the number in each interval has been expressed as a percentage of the total number of waves which occurred in the two years. The results have been expressed diagrammatically in fig. 8, in which the percentage occurring in the interval 6 to 10 hours has been plotted against the 8-hour point, that occurring in the interval 11 to 15 hours against the 13-hour point, etc.

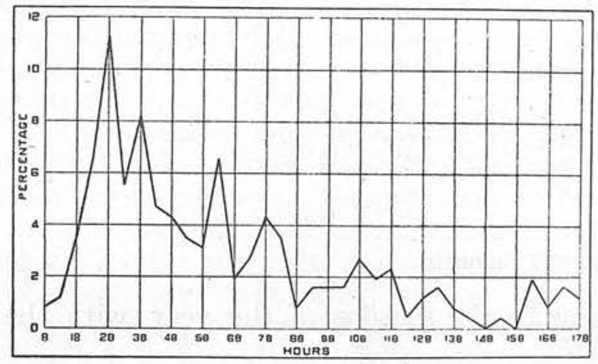


Fig. 8.—Percentage frequency of pressure waves of different periods.

The figure indicates maximum frequencies for waves of a mean period of 28, 38, 63, 78, and 108 hours, but there seems to be no indication of any relationship between these mean periods or any other period which is common to these periods. Waves of a mean period of 28 hours are more frequent than waves of any other period, a percentage of 11·3 of the waves having their periods in the interval 26 to 30 hours. The high percentage of 23·4 of the waves have their periods lying in the interval 21 to 35 hours.

The data have been examined to find the number of waves whose amplitudes lie within specified ranges, and the results have been entered in Table 37 together with the wave-length of the corresponding wave.

Table 36.—Number of Pressure Waves and Amplitudes of the Waves of Different Periods.

Year.	Interval in Hours.							
	⩽ 50	51–100	101–150	151–200	201–250	251–300	Longest.	Total Number.
	Number of Waves.							
1882–83	49	40	13	8	4	1	281	115
1932–33*	70	41	20	7	1	1	303	141
	Amplitude of Waves in Millibars.							
1882–83	17·3	21·9	30·4	25·1	37·7	25·0	25·0	
1932–33*	17·1	16·2	23·9	30·7	21·4	31·9	31·9	

* Thirteen months.

Table 37.—Number of Pressure Waves and Lengths of the Waves of Different Amplitudes.

Year.	Range of Amplitudes in Millibars.				Max. Amplitude.
	6·7–13·4.	13·4–20·0.	20·0–26·7.	> 26·7.	
	Number of Waves.				mb.
1882–83	26	30	29	30	50·6
1932–33	44	46	26	25	46·3
	Length of Waves in Hours.				
1882–83	77·6	141·8	167·2	205·6	
1932–33	83·0	113·4	168·4	219·3	

6. PRESSURE SURGES

The long period waves upon which are superimposed the pressure waves were first studied by Simpson. These lóng waves, which are called pressure surges, are obtained by smoothing out the smaller pressure waves. Following Simpson's procedure of smoothing, consecutive ten-day means have been formed from the mean daily values of the pressure during the year 1932–33, and the resulting pressure curve is represented in fig. 9, which has been obtained by plotting the mean pressure from the 1st to the 10th of any month against the 5th, the mean pressure from the 2nd to the 11th against the 6th, etc.

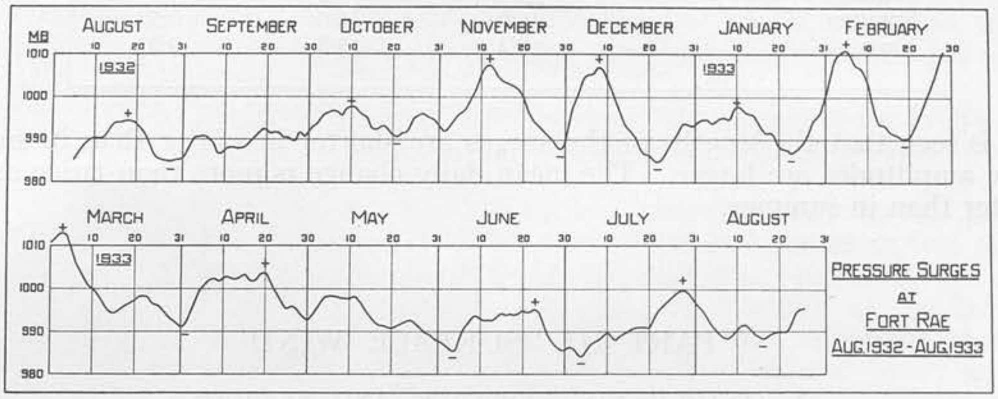


FIG. 9.

An obvious characteristic of the resulting pressure curve is that the surges are much better developed during the winter and spring than during the summer and autumn months. There are four well-developed surges in the months of November, December, early February, and early March.

In order to determine further characteristics of the pressure surges, a criterion similar to that used by Simpson has been applied to the consecutive ten-day means. The periods and amplitudes have been determined for these surges for which the difference between the maximum and the following minimum, and the difference between this minimum and the following maximum are both greater than 6·67 mb. The maxima and minima which satisfy this condition have been represented in the figure by a positive and negative sign respectively. The days of occurrence of the maximum and minimum with the ten-day mean pressure are entered in Table 38.

TABLE 38.—TIMES OF OCCURRENCE AND VALUES OF MAXIMA AND MINIMA OF PRESSURE SURGES.

Maxima.		Minima.	
Date.	Pressure (mb.).	Date.	Pressure (mb.).
1932 August 18	994·27	1932 August 28	984·90
October 10	997·96	October 21	990·92
November 12	1007·62	November 29	987·87
December 8	1006·95	December 22	984·74
1933 January 10	997·84	1933 January 23	986·74
February 5	1010·98	February 19	990·20
March 3	1013·01	March 31	991·23
April 20	1003·61	June 3	985·50
June 23	995·09	July 4	984·04
July 28	999·76	August 16	988·08

The lengths and amplitudes of the surges are entered in Table 39, where the winter covers the period from the minimum on 1932 October 21 to the maximum on 1933 April 20, and the summer the residual period.

TABLE 39.—LENGTHS AND AMPLITUDES OF THE PRESSURE SURGES.

Season.	Length.	Amplitude.	Mean Daily Change.
	Days.	mb.	mb./day.
Winter	33·0	18·5	1·12
Summer	45·6	11·9	0·52
Year	38·2	15·8	0·83

It is seen that the lengths of the surges are shorter in winter than in summer, but the amplitudes are larger. The mean daily change is more than twice as great in winter than in summer.

PART III.—SURFACE WIND

1. INSTRUMENTS, EXPOSURE, AND METHODS

(a) *Instruments and exposure.*—In order to record the wind velocity at Fort Rae, three anemometers were erected at suitable sites, two of them being subsidiary anemometers which were to be used in the event of a breakdown with the Dines pressure tube anemometer.

The Dines pressure tube anemometer was of the standard pattern as used in most of the British meteorological stations, and a full description of the instrument is to be found in the *Observer's Handbook*, 1934. The recorder was set up near the middle of the main station, and the mast was erected vertically above, through the roof. The pressure opening at the head was at a height of 25 ft. 6 in. above the roof and at a height of 45 ft. 1 in. above the level of the floor. The head had an excellent exposure from all directions.

Normally, the outlets at the base of the anemometer head are connected by brass unions to steel or copper pipes of 1 in. bore, which transmit the variations of pressure to the velocity recorder. At Fort Rae, however, the steel or copper pipes were replaced by a reinforced rubber pipe of 1 in. bore, which withstood the severe weather of the winter admirably. The rubber pipes were tested several times during the year, and at the conclusion of the expedition, for leaks, and on all occasions they were found to be in good condition, no leaks having developed.

During the onset of cold weather some difficulty was at first experienced in keeping the air in the main station above the freezing-point and so preventing the water in the tank of the recorder freezing. The difficulty was overcome by lagging the tank with cotton-wool, and building around the tank a cupboard in which a small stove could be placed during periods of extreme cold.

The greatest difficulty, however, occurred in making the pens of the velocity and direction recorders function during the winter months. Numerous methods were attempted, but without much success. The trace during the winter months gave no difficulty in obtaining the mean wind for the hours, but owing to the manner in which the pens functioned there was frequently a cut-off during gusts or lulls. This was decidedly noticeable during strong winds, though the mean wind was well marked.

The Dines pressure tube anemometer was considered as the standard instrument, and all the analyses of the wind refer to the records of this instrument.

A Robinson cup anemometer, which consisted of four cups attached to the ends of two crossed metal arms, was erected, in the first place, on the roof of the dwelling-house, but later, owing to the difficulty of reading the instrument, it was removed to a site near the Stevenson screen. The instrument was considered as an emergency instrument in the event of failure of the Dines anemometer. It was read at 8h daily.

A wind vane, below which was suspended a pressure plate which enabled the wind force to be read in the Beaufort scale, was erected on the north end of the ridge of the main station. No regular readings were taken.

(b) *Method of reading the anemometer records,* 1932–33.—The charts were changed on the Dines anemograph at 8h daily, and two time marks were made at 11h and 23h respectively. The details for the care of the anemograph are fully given in the *Observer's Handbook,* and all these details were attended to in order to ensure an accurate record.

Before the tabulation of a record was begun it was examined for faulty timing and for zero error, and any allowances made on account of these defects have been incorporated in the final tabulated values.

The mean hourly values of wind speed and direction refer to the period of 60 mins., ending at the exact hours of zonal mean time, and the mean was obtained by drawing in imagination a continuous line through the centres of the narrow vertical sections of the trace and then estimating the position of the horizontal line such that the areas between it and the continuous line, occurring above and below the horizontal line, are equal. The values were estimated to 0·1 m/s. To assist in the estimation, a celluloid scale with a transparent vertical section exactly 60 mins. wide, and having appropriate horizontal lines for estimating to the nearest 0·1 m/s for velocity and to the nearest 5° for direction, was used. Consequently, for 1932–33 all the hourly values of the wind velocity and direction cover a period of 60 mins., centred at the half-hour of zonal mean time, and extend from July 1932 to August 1933 inclusive.

(c) *The wind results for* 1882–83.—All the information given by Captain Dawson concerning the observation of wind has already been given in the introduction to the meteorological discussion. It is noticed that two cup and dial anemometers were in use, one upon the hill to the north-east of the station and the other on an island in the lake, but no use had been made of this latter anemometer owing to the snow frequently affecting its mechanism. An observation of the anemometer, presumably the one on the hill, was made every hour, together with an observation of wind, presumably one in the Beaufort scale. Apparently the observations from the anemometer were not published, as Captain Dawson states that "The estimated force by Beaufort's scale has been used in the reductions, a comparison having shown a close agreement with the anemometer readings." No record is available of this comparison in the original published data.

Furthermore, the published hourly values of wind velocity are given in whole metres per second (m/s), and though, from the preceding statement, they must have been based upon the Beaufort estimate, no record is given of the scale of conversion from the Beaufort into whole m/s. The only data that are available are the hourly values of wind in whole m/s. Even the basic Beaufort estimates are not available. Captain Dawson gives no reasons for not publishing the direct hourly anemometer readings, and gives no record of the scale of conversion from his hourly unpublished Beaufort estimates to whole m/s.

No information is given as to how the wind direction was determined, whether the direction refers to the wind at the anemometer site or whether it refers to an estimate made when taking the Beaufort force. The plan of the Old Fort Rae station (p. 18) shows a vane at the end of the north-east gable of the unfinished building, but it is not stated whether the direction of this vane was used in determining the hourly values of wind direction.

Owing to the indeterminancy which relates to the wind observations, the hourly values as published have had to be accepted, and these hourly values give the velocity in whole m/s and the direction to 16 points, at the exact hours of local mean time. The hourly values are available from September 1882 to August 1883 inclusive.

The wind observations for the separate years are not homogeneous, and whenever the results have been combined, the method has been to reduce the values for the year 1882–83 to a form suitable for combination with the values for the year 1932–33.

2. ANNUAL VARIATION OF WIND VELOCITY

Table 40 contains the mean monthly velocities of the wind for the two years entered to the first place of decimals.

TABLE 40.—MEAN MONTHLY WIND VELOCITY.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean.
	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
1882	..	..	..	..	..	..	..	..	3·0	2·9	2·4	1·5	
1883	1·4	2·4	2·1	2·3	2·5	2·5	2·7	2·6	..	..	..	..	2·4
1932	..	..	..	..	..	..	4·2	4·3	4·9	4·9	5·4	3·9	
1933	2·9	4·7	4·3	4·8	4·2	4·7	4·1	4·8	..	..	..	..	4·4
Mean	2·1	3·5	3·2	3·5	3·3	3·6	3·4*	3·6*	3·9	3·9	3·9	2·7	3·4

* Mean value determined from expression: $\text{Mean} = \frac{1}{3}\left[83 + \frac{32+33}{2}\right]$.

The monthly mean values of the wind velocities have been represented diagrammatically for the two years in fig. 10.

An examination of the table or the figure shows that the mean velocity for the individual months for the year 1932–33 is approximately twice as great as

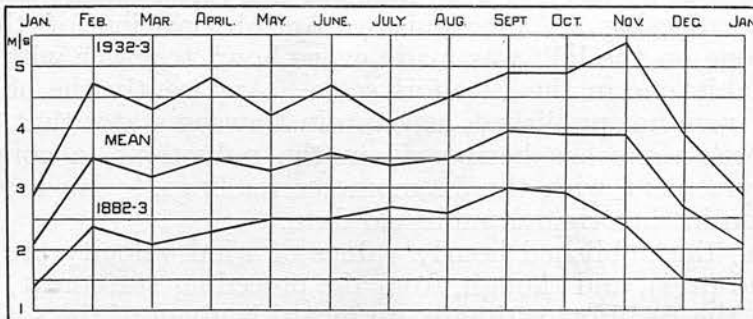


FIG. 10.—Annual variation of wind velocity.

the mean velocity for the corresponding months for 1882–83. In this respect, however, it must be remembered that during 1882–83 the mean values are based upon Beaufort estimates of wind force at the surface, whereas during 1932–33 the mean values are determined from records which give the velocity at the height of the pressure orifice of the Dines anemometer, which was 45 feet above the surface. It is therefore expected that the values determined in 1932–33 would exceed the values determined for 1882–83.

Nevertheless, the two curves for the individual years show great similarity in their general character. The maximum wind velocity occurs during the autumn or early winter, from September to November, after which there is a rapid fall in the mean monthly value, reaching its minimum in January. The mean velocity again increases from January to February, after which it remains fairly steady, with a tendency to increase as the year progresses, to reach its maximum in the autumn.

The mean curve probably represents fairly accurately the curve of annual variation of wind in the locality of Fort Rae, showing a single annual period with a maximum in the autumn and a minimum in the coldest month of January.

3. DIURNAL VARIATION OF THE WIND VELOCITY

(a) *Diurnal inequalities: all days.*—Owing to the fact that during the year 1882–83 the results have been based upon the wind force estimated according to the Beaufort scale and later converted into m/s, it was decided to omit the diurnal inequalities of wind for that year from the present discussion and to base it entirely upon the results for the year 1932–33.

Table 7, Vol. II, gives the diurnal inequalities of wind velocity for the months and seasons of the year where the maximum and minimum hourly values for the months and seasons have been underlined.

The values for the months have been plotted against time in fig. 11 and the resulting points connected by a smooth line. The inequalities plotted for July and August, however, are the mean inequalities for the combined months of the two years.

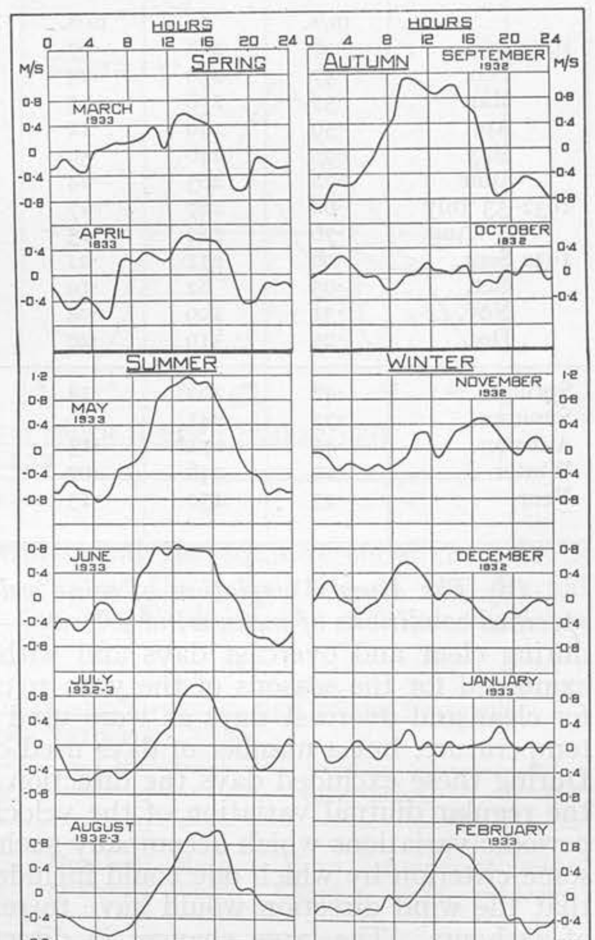


FIG. 11.—Diurnal variation of wind velocity, 1932–33.

An examination of the table or the curves show general similarities for all months from February to September. The inequalities are positive during the day and negative during the night, the maximum values occurring after midday and the minimum values generally during the early hours of the morning or a few hours before midnight. This type of diurnal variation is the normal type in which the convection currents, which during the day-time transport kinetic energy down to the ground, appear to be responsible for the variation.

The two spring months, March and April, show other similarities. There are secondary maxima at 10–11h and at 20–22h during March, and at 9–10h and 23–24h during April. Thus during these months one of the secondary maxima precedes the main maximum of the day by 3 to 4 hours, whereas the other secondary maximum occurs a little before midnight.

During the months October to January the inequalities are rather irregular, though the maximum for both November and December occurs during the day-time. In October the principal maximum, and in December a secondary maximum, occur during the early hours of the morning.

The annual variation of the amplitude of the diurnal inequalities shows that the maximum amplitude occurs during the summer months and the minimum during the winter months.

The inequalities have been analysed harmonically, and the results of the analysis giving the values of the coefficients and the phase angles have been entered in Table 41. The analysis leads to no new results.

TABLE 41.—HARMONIC COEFFICIENTS OF THE DIURNAL INEQUALITY OF WIND VELOCITY AT FORT RAE, 1932–33.

Values of c_n, α_n in the series $c_n \sin(15nt+\alpha_n)$, t being Zonal Mean Time reckoned in hours from midnight.

Month and Season.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
	m/s.	°	m/s.	°	m/s.	°	m/s.	°
1933 Jan.	·08	208	·07	210	·04	22	·04	163
Feb.	·47	250	·29	14	·04	210	·08	28
Mar.	·37	278	·15	40	·15	168	·09	246
Apr.	·50	249	·11	71	·09	111	·07	234
May	·95	246	·30	41	·09	290	·02	107
June	·72	265	·24	37	·07	326	·08	186
1932–33 July	·60	227	·27	39	·11	155	·07	99
Aug.	·76	222	·25	28	·02	195	·04	220
1932 Sept.	·96	271	·22	90	·08	226	·21	234
Oct.	·05	82	·10	54	·07	254	·07	234
Nov.	·31	199	·04	23	·06	41	·13	167
Dec.	·25	319	·20	119	·10	35	·11	286
Spring	·42	262	·12	53	·11	147	·08	243
Summer	·73	241	·26	37	·02	257	·03	154
Autumn	·45	271	·15	80	·07	239	·14	234
Winter	·20	246	·07	55	·04	36	·02	209
Year	·45	250	·15	48	·01	180	·05	219

(b) *The diurnal variation of wind velocity during clear and overcast days under specified conditions of mean wind velocity.*—The diurnal variation of the wind velocity during clear and overcast days and with different mean wind velocities has been examined for the seasons of the year 1932–33. The same criteria have been used for clear and overcast days as were used when discussing the diurnal variation of temperature, but a number of days used on that occasion have now to be excluded. During these excluded days the direction of the wind changed considerably, so that the regular diurnal variation of the velocity disappeared because of the large non-periodic variations which accompany such changes of direction. In order to obtain some criterion by which one could include or exclude a definite day, it was decided that the wind direction would have to remain fairly steady in direction for 18 out of 24 hours. The large changes in direction of the wind mainly occurred during days when the mean wind velocity was small, and it was comparatively easy to apply the above criterion to all days under consideration.

The diurnal inequalities, smoothed according to the formula $4\bar{b}=a+2b+c$, for the seasons of the year have been entered in Table 8, Vol. II, and the values have been plotted against time in fig. 12.

The characteristics of the days under consideration have also been entered in Table 42.

The results are difficult to explain. The mean cloud amounts during overcast days are practically the same for all seasons, and during clear days the differences are comparatively small, so that we may say that the conditions of the sky are the same for overcast days during all seasons and similarly for clear days.

But for overcast days during the winter and the equinox the amplitude of the diurnal variation of wind velocity increases with increasing wind velocity. During the summer, however, the reverse is the case, and the amplitude of the diurnal variation decreases with increasing wind velocity.

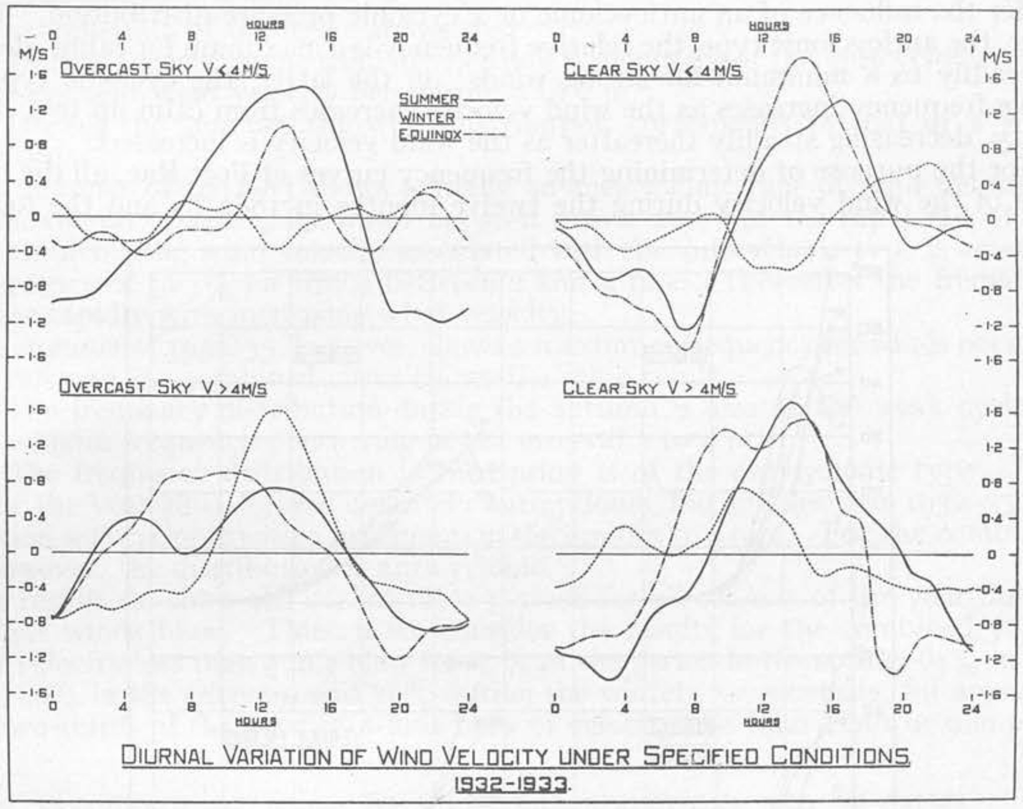


FIG. 12.

If we consider the clear days, the winter and the equinox show the reverse phenomenon, that with increasing wind velocity the amplitude of the diurnal variation decreases. During the summer the amplitude of the diurnal variation increases with increasing wind velocity.

TABLE 42.—CHARACTERISTICS OF DAYS OF CLEAR AND OVERCAST SKY UNDER SPECIFIED LIMITS OF WIND VELOCITY.

Season.	Velocity Limits.	Overcast Days. Mean Wind.	Mean Cloud.	Ampli-tude.	Number of Days.	Clear Days. Mean Wind.	Mean Cloud.	Ampli-tude.	Number of Days.
	m/s.	m/s.	tenths.	m/s.		m/s.	tenths.	m/s.	
Winter .	0·0–4·0	2·81	9·1	0·69	10	2·55	1·6	1·20	15
Summer		2·69	9·0	2·65	5	3·22	1·9	2·59	10
Equinox		3·03	9·3	1·46	12	2·48	1·4	3·29	6
Winter .	> 4·0	6·79	9·2	2·35	14	6·10	0·7	1·14	9
Summer		7·01	9·3	1·61	19	4·69	2·2	3·11	6
Equinox		6·42	9·4	2·09	21	6·57	1·7	2·88	8

4. FREQUENCY OF WINDS OF DIFFERENT VELOCITIES

Simpson * has shown that the type of frequency curve differs for a locality which is under the influence of an anticyclonic or a cyclonic pressure distribution. In the former, the anticyclonic type, the relative frequency is a maximum for calms, decreasing steadily to a minimum for strong winds; in the latter, the cyclonic type, the relative frequency increases as the wind velocity increases from calm up to a certain velocity, decreasing steadily thereafter as the wind velocity is increased.

For the purpose of determining the frequency curves at Fort Rae, all the hourly values of the wind velocity during the twelve months in 1882–83 and the fourteen

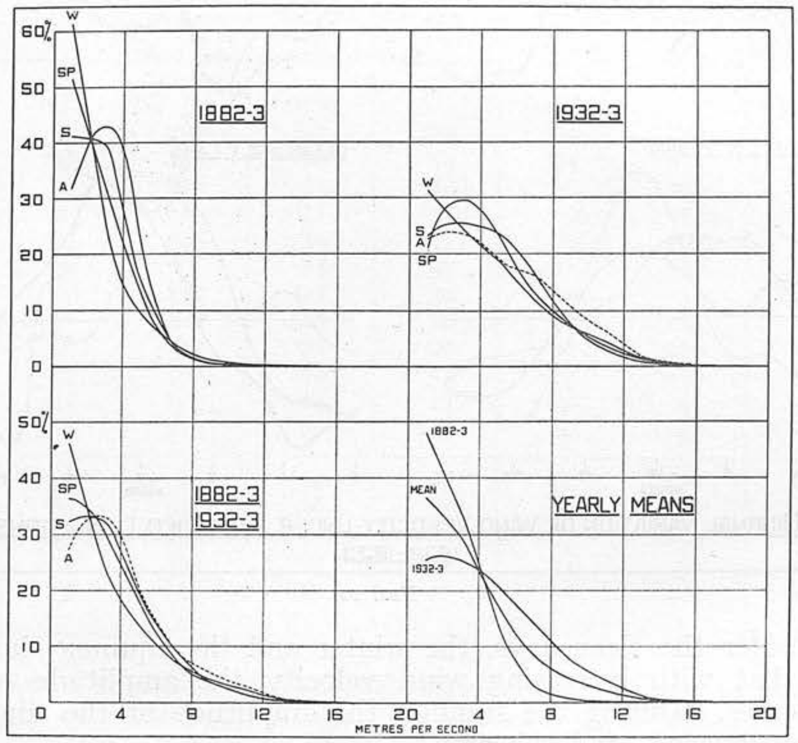


FIG. 13.—Frequency of winds of different velocities.

months in 1932–33 have been analysed and percentage frequencies obtained for each month of the two years. The data for the two years were not homogeneous, as has previously been explained, so that the data had to be treated in different ways in order to be able to combine the results for the two years.

The methods adopted follow those used by Sverdrup † when combining similar non-homogeneous data. For the year 1932–33 the relative frequencies of velocity in the intervals 0 to 2 m/s, 2·1 to 4 m/s, 4·1 to 6 m/s, etc., were computed, but for the year 1882–83 the number of cases were first found in which 0, 1, 2, 3 m/s, etc., had been entered in the published hourly values. The number of cases in which 2 m/s was entered was then distributed to the neighbouring groups of 0 to 1 m/s and 3 m/s. The group 4 m/s was distributed between the group 3 m/s and 5 m/s, etc., so that the final grouping was made around the velocities 1 m/s, 3 m/s, 5 m/s, etc. These values of the velocity are mean values for the intervals 0 to 2 m/s, 2·1 to 4 m/s, 4·1 to 6 m/s, etc., and so, when expressed in percentages, can be combined with the percentage frequencies for the year 1932–33.

The relative frequencies for each month and season of the individual years, together with the results for the combined seasons, are given in Table 9, Vol. II, and

* G. C. Simpson, *British Antarctic Expedition, 1910–13*, pp. 103–107.

† H. U. Sverdrup, Bergen, *Norwegian North Polar Expedition with the "Maud," 1918–25*, p. 231.

the results for the seasons of the individual years and the seasons for the combined years have been plotted in fig. 13. In the figure the values corresponding to the interval 0 to 2 m/s have been plotted against 1 m/s; the values corresponding to 2 to 4 m/s against 3 m/s, etc.

An examination of the figure shows that

(*a*) During the winter the wind distribution is definitely of the anticyclonic type, the most frequent wind velocity being from 0 to 2 m/s.

(*b*) During the summer the wind distribution corresponds to that of a weak cyclonic type.

The summer of 1882–83 shows actually an anticyclonic type of wind frequency with a maximum of 41·2% for winds between 0 to 2 m/s, but the rapid fall of the curve with increasing wind velocity associated with the anticyclonic type is arrested by a frequency of 39·3% for winds between 2 and 4 m/s. Thereafter the frequency diminishes rapidly with increasing wind velocity.

The summer of 1932–33, however, shows a maximum frequency for winds between 2 and 4 m/s and the combined curve shows the same result.

(*c*) The frequency distribution during the autumn is also of the weak cyclonic type, maximum frequencies occurring in the interval 2 to 4 m/s.

(*d*) The frequency distribution in the spring is of the anticyclonic type. The spring for the year 1882–83 was definitely anticyclonic, but for the year 1932–33 the distribution was cyclonic with a maximum in the limits 2 to 4 m/s. For the combined years, however, the distribution is anticyclonic.

The results do show the considerable periods for all seasons of the year during which light winds blow. Thus, if we consider the results for the combined years, winds of velocity less than 4 m/s blow for 67% of the period in the spring, 64% in the summer, 60% in the autumn, and 70% during the winter; or generally, for approximately two-thirds of the seasons, winds blow of velocity less than 4 m/s or 9 m.p.h.

5. FREQUENCY OF WINDS OF DIFFERENT DIRECTIONS AND OF CALMS

In order to determine the frequency of winds from different directions, the hourly values of the wind velocity were analysed with respect to the 16 points NNE., NE., ENE., etc. The data for the year 1882–83 are already given for these 16 points, but the values for 1932–33 are given to the nearest 5°. For this year, therefore, all winds blowing from 12° to 34° are considered as NNE. winds, from 35° to 57° as NE. winds, from 58° to 78° as ENE. winds, etc.

Calms have been considered separately, and for this purpose, during the year 1882–83, owing to the method of observing in the Beaufort scale with a later conversion into whole m/s, the wind velocities entered in the tables as 1 m/s or above have been excluded from calms. It is usual, however, when considering the analysis of wind from the records of the Dines anemograph, to treat winds from 0 to 1·5 m/s as calm. Consequently, for the year 1932–33 all winds below or equal to 1·5 m/s have been treated as calm, and all winds greater than 1·5 m/s have been entered into their appropriate direction.

With this understanding, Table 10, Vol. II, has been prepared, which gives the percentage frequency of winds from the 16 points for the months, seasons, and year, together with the similar results for the seasons of the combined years. An extract from this table for the seasons of the year has been entered in Table 43.

An examination shows that calms are more frequent in both years during the winter months December, January, and February, with a maximum in the coldest month of January. The annual variation consists mainly of a single period with a maximum in the winter and a minimum in the autumn.

As regards the wind directions, it is obvious that for all the seasons, and in fact for every month of the two years, there are two principal maxima, and the percentages for these directions have been entered in characteristic type in the tables. In general, the directions of the principal maxima are SE. to ESE. and NW. to

NNW. These directions occur so frequently in the later discussion that winds from the SSE. to ESE. will be called the SE. type and winds from the N. to NW. will be called the NW. type.

TABLE 43.—SEASONAL PERCENTAGE FREQUENCY OF WINDS FROM DIFFERENT DIRECTIONS AND OF CALMS.

Season.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.	N.	Calm.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
									1882–83.								
Spring .	3·9	0·9	5·3	3·5	37·9	5·7	2·1	..	0·1	..	..	0·1	0·9	1·3	17·3	3·3	17·7
Summer	5·8	1·9	4·8	7·8	24·9	4·3	8·4	1·1	3·2	0·9	1·4	0·7	6·1	2·1	13·9	4·6	8·2
Autumn	4·3	1·5	6·9	9·3	16·0	7·5	6·7	3·4	4·7	2·7	1·2	1·8	3·5	8·1	14·1	4·2	4·0
Winter .	1·9	1·2	2·9	1·6	13·0	2·6	3·0	1·1	2·2	0·8	0·3	0·4	5·8	3·5	25·6	5·9	28·1
Year .	3·9	1·4	4·6	5·3	21·6	4·5	5·3	1·3	2·6	1·0	0·8	0·7	4·7	3·4	18·4	4·7	15·7
									1932–33.								
Spring .	4·1	5·8	3·5	3·4	4·7	15·7	7·7	0·8	0·1	0·2	0·2	1·3	0·8	6·3	20·5	9·7	15·1
Summer	3·4	2·9	2·1	4·2	4·5	16·8	10·1	3·9	1·2	1·7	1·1	2·1	2·5	8·2	10·0	7·0	18·3
Autumn	1·6	1·1	2·3	5·2	4·9	13·1	7·5	2·4	1·9	2·3	1·9	3·9	5·3	12·0	7·6	10·6	16·3
Winter .	3·1	1·5	1·2	1·2	2·1	8·5	3·6	0·4	0·1	0·6	1·3	8·6	7·3	12·6	14·3	8·4	25·1
Year .	3·1	2·6	2·1	3·2	3·8	13·3	7·1	1·9	0·8	1·2	1·1	4·4	4·3	10·0	12·8	8·5	19·7
									Combined Years.								
Spring .	4·0	3·3	4·4	3·5	21·3	10·7	4·9	0·4	0·1	0·1	0·1	0·7	0·9	3·8	18·9	6·5	16·4
Summer	4·6	2·4	3·5	6·0	14·7	10·5	9·3	2·5	2·2	1·3	1·3	1·4	4·3	5·1	11·9	5·8	13·3
Autumn	2·9	1·3	4·6	7·3	10·5	10·3	7·1	2·9	3·3	2·5	1·5	2·9	4·4	10·1	10·9	7·4	10·1
Winter .	2·5	1·3	2·1	1·4	7·6	5·5	3·3	0·7	1·2	0·7	0·8	4·5	6·5	8·1	19·9	7·2	26·6
Year .	3·5	2·0	3·4	4·3	12·7	8·9	6·2	1·6	1·7	1·1	0·9	2·5	4·5	6·7	15·6	6·6	17·7

If the results for the combined years be considered, the maximum frequency during the spring and summer occurs with the SE. type and a secondary maximum with the NW. type. For the autumn and winter the maximum frequency occurs with the NW. type and a secondary maximum with the SE. type. The above statements, however, do not hold from year to year. In order to bring into prominence these two prevailing wind directions the percentage frequencies for the SE. and NW. types have been grouped together for the seasons of the respective years in Table 44.

TABLE 44.—PERCENTAGE FREQUENCY OF SE. AND NW. TYPES AND OF CALMS.

Season.	1882–83.				1932–33.			
	SE. Type.	NW. Type.	Calm.	Total.	SE. Type.	NW. Type.	Calm.	Total.
	%	%	%	%	%	%	%	%
Spring	45·7	21·9	17·7	85·3	28·1	36·5	15·1	79·7
Summer .	37·6	20·6	8·2	66·4	31·4	25·2	18·3	74·9
Autumn .	30·2	26·4	4·0	60·6	25·5	30·2	16·3	72·0
Winter . .	18·6	35·0	28·1	81·7	14·2	35·3	25·1	74·6
Year . .	31·4	26·5	15·7	73·6	24·2	31·3	19·7	75·2

The table shows that for more than half the time during the summer, autumn, and winter, and for about two-thirds of the time during the spring, the winds are

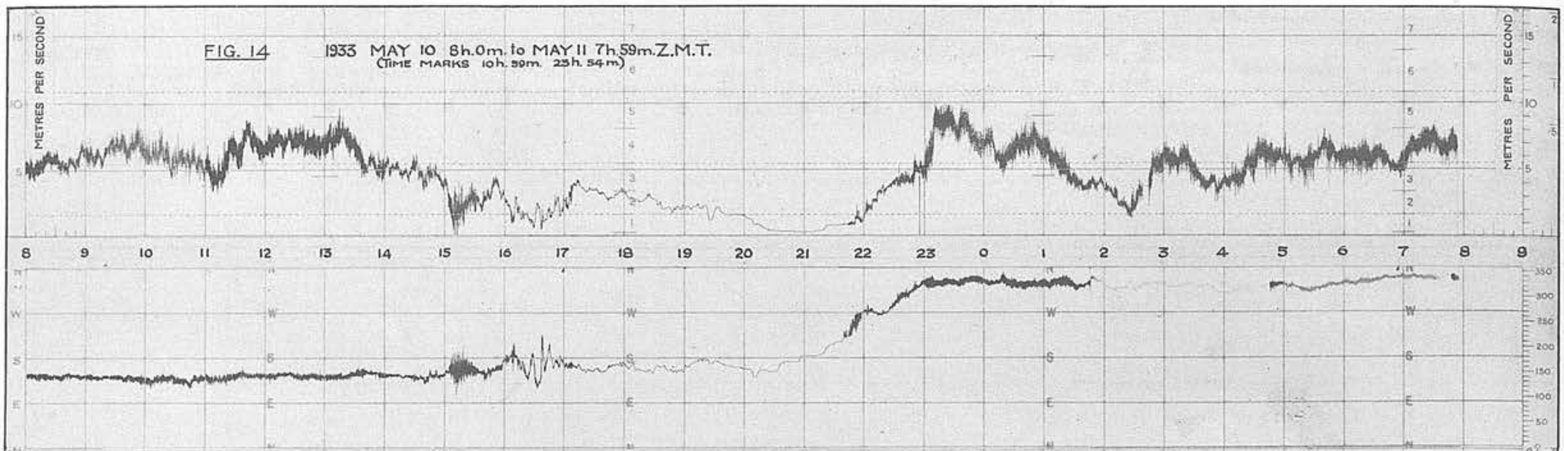


FIG. 14 1933 MAY 10 8h.0m. to MAY 11 7h.59m. Z.M.T. (TIME MARKS 10h.59m. 23h.54m.)

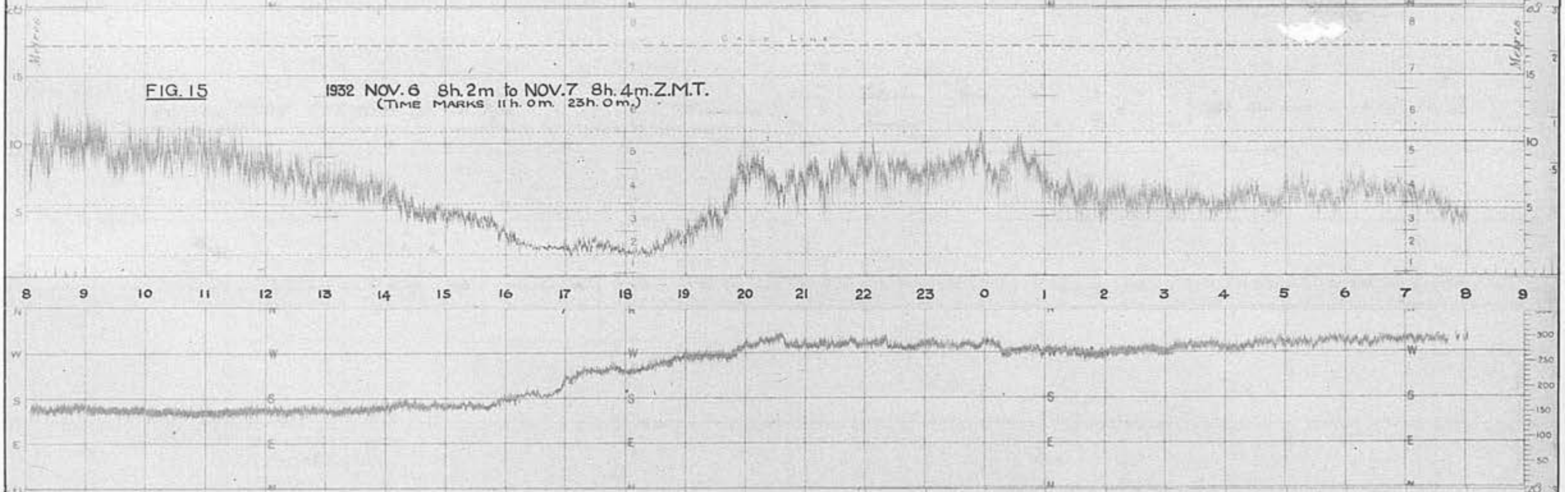


FIG. 15 1932 NOV. 6 8h.2m to NOV. 7 8h.4m. Z.M.T. (TIME MARKS 11h.0m. 23h.0m.)

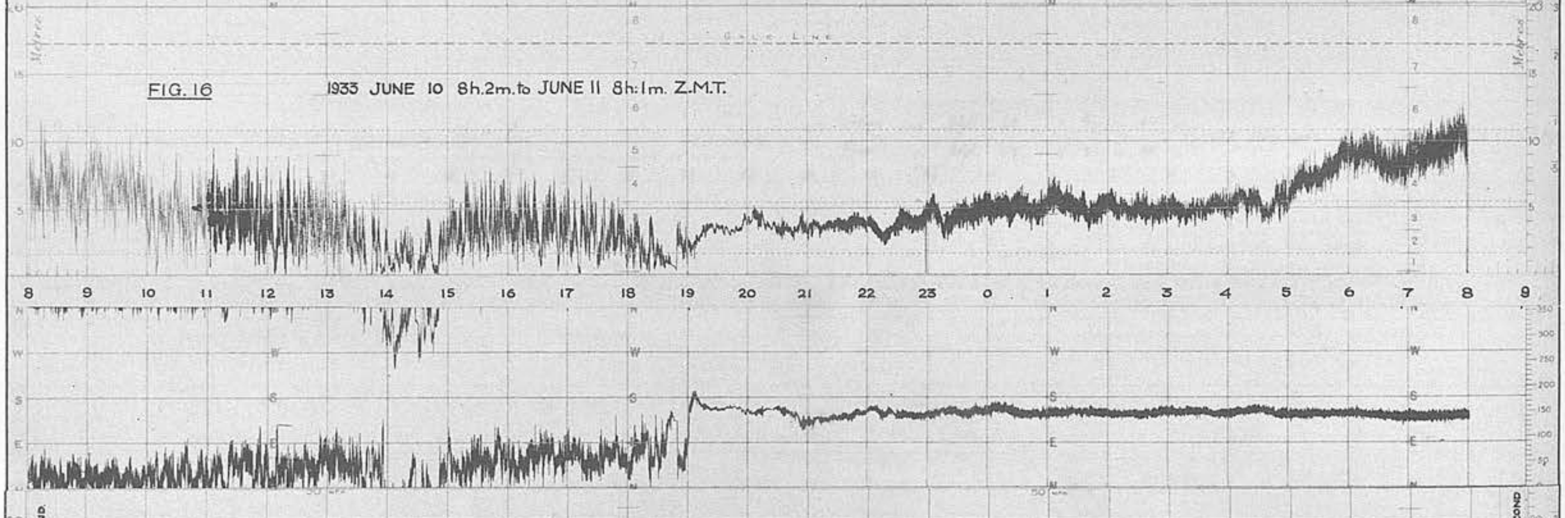


FIG. 16 1933 JUNE 10 8h.2m. to JUNE 11 8h.1m. Z.M.T.

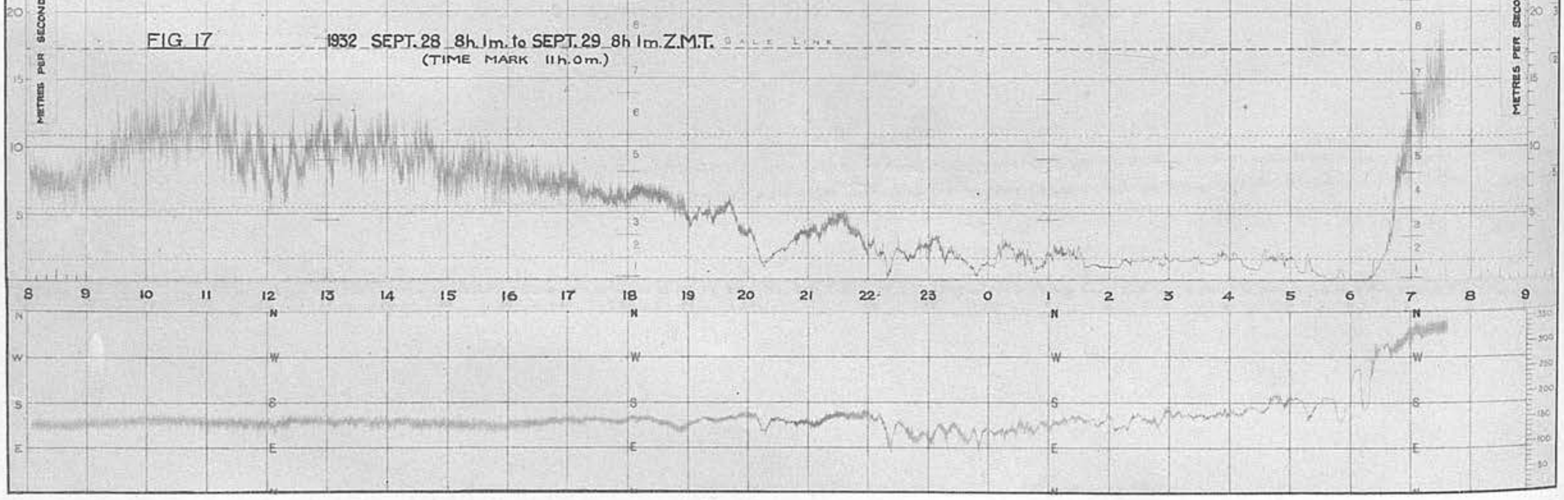


FIG. 17 1932 SEPT. 28 8h.1m. to SEPT. 29 8h.1m. Z.M.T. (TIME MARK 11h.0m.)

either of the SE. or the NW. type. If account be also taken of the percentage frequency of calms, the total time during which the wind is either NW., SE., or calm is particularly high for all seasons of the year.

6. THE SOUTH-EASTERLY AND THE NORTH-WESTERLY WIND AT FORT RAE, 1932–33

The two prevailing wind directions which are indicated from the results of the two years' data were exceedingly well marked at Fort Rae during 1932–33, and the anemograph records show the constant shift of wind from the NW. type to the SE. type, and *vice versa*. The effect of these two prevailing wind directions upon the temperature, pressure, wind, and cloud will be discussed at a later stage. At present some anemograph records are given which show the shift of wind direction from the one type of wind direction to the other.

In general, the change from one direction to the other was of the following nature: For one, two, or three days the wind would blow from the SE. with slightly varying velocity, after which the velocity would decrease to a calm. The calm would continue for a few hours, after which the wind would veer to the NW.; the velocity of the wind would increase at first and then continue of varying strength for one, two, or three days. A similar process would take place for a change of wind from the NW. to the SE.

In fig. 14 is reproduced one of the numerous anemograph records showing the change of wind from the SE. to the NW. type. The record was obtained on 1933 May 10–11, and it shows the period of calm or light wind which prevails from 17h to nearly 22h between the change of direction from SE. to NW.

During other periods of change there was no interval in which calms prevailed, but the wind veered steadily from the SE. to the NW. Fig. 15 is the reproduction of a record made on 1932 November 6–7, which shows the steady veer of the wind between the change of types. The record shows that before 16h the wind was blowing from the SSE. with decreasing wind velocity. At 16h the light wind began to veer and continued veering with increasing wind velocity until 20h 30m, thereafter continuing in a W. to W by N. direction.

Fig. 16 represents the wind record on 1933 June 10–11, and shows the change of wind from a NE. direction to a SE. direction. The change of direction is a rapid one, and it has the character of a marked frontal change. There is, however, another feature to which attention must be drawn. Before 19h the wind blows from the NE., but the mean wind velocity is small and the gustiness large. After 19h the wind changes to SE., and though the wind velocity is as great as, and even greater, at the end of the record than with the NE. wind, yet the gustiness is comparatively small. There is a striking difference in the character of the trace before and after the change. In general, the large gustiness was a characteristic of NE. winds at Fort Rae.

It has been stated that some of the changes in wind direction have the character of a frontal change. In general, there was no obvious change in some of the other meteorological elements, such as temperature, pressure, humidity, etc., during the change of wind direction. The whole question of fronts has not yet been studied, but there were a few cases in which the change of wind direction from the SE. to the NW. were obviously changes due to the passage of fronts. Fig. 17 is a reproduction of an anemograph record which shows the rapid change of wind direction and velocity which occurred at 6h 45m to 7h on September 29, 1932.

For the preceding day the wind had been SE., fresh at first, moderating during the evening, and had dropped to calm during the morning of September 29. After a short period of calm the wind veered rapidly to the NW., increasing in strength and attaining a velocity of 16 m/s by 8h. There were simultaneous rapid changes in temperature, pressure, and humidity. The temperature had remained fairly steady at about 5·0° C. during the early hours of the morning, but at 7h the temperature rose within 15 minutes by 2·6° C. The pressure had continued falling from the morning of September 27 to a minimum pressure of 973·5 mb. between 6h and 7h on September 29. After 7h the pressure increased rapidly, rising 2 mb. within the hour and 3·7 mb. within 3 hours. The relative humidity fell between 7h and 8h from 93% at 7h to 79% at 8h. This front would be associated with the depression which moved from the Aleutian Islands on the morning of September 28, and was centred over the Beaufort Sea on the morning of September 29.

Such obvious changes in the meteorological elements accompanying the change in direction of the surface wind were not general, and only a few similar cases are to be found in all the records.

7. VELOCITY OF WINDS FROM DIFFERENT DIRECTIONS

The method adopted for determining the frequency of winds from the different directions was also employed for determining the mean velocity of winds from the respective directions, so that in the analysis, winds of velocity less than or equal to 1·5 m/s for 1932–33 and winds of 0 m/s in 1882–83 were taken as calm. Consequently a mean velocity for a certain direction cannot be less than 1·5 m/s during 1932–33, but the mean velocity can well be less than 1·5 m/s during the year 1882–83.

Table 11, Vol. II, gives the results of the computation for the two years, and the values in the brackets indicate that there are ten or less observations included in the determination of the mean velocity. An abstract from this table for the seasons of the respective years and for the combined years has been entered in Table 45.

TABLE 45.—SEASONAL MEAN WIND VELOCITY FROM VARIOUS DIRECTIONS EXCLUSIVE OF CALMS.

Season.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.	N.
	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
								1882–83.								
Spring .	1·4	1·7	1·8	1·6	2·6	4·2	2·9	..	(1·0)	..	..	(2·0)	3·1	4·3	2·9	2·0
Summer .	1·8	1·7	2·4	2·8	2·8	3·2	3·1	3·6	2·5	2·6	1·9	1·5	2·9	2·6	3·3	2·9
Autumn .	2·5	2·4	2·1	2·7	3·7	3·4	3·4	3·5	3·7	3·3	3·8	2·5	2·1	2·8	3·3	2·3
Winter .	1·9	1·5	1·5	1·1	2·2	2·1	2·8	3·6	3·1	2·7	(2·7)	(1·9)	2·4	3·0	3·2	2·3
Year . .	1·9	1·8	2·0	2·4	2·8	3·3	3·1	3·6	3·0	2·9	2·5	2·0	2·6	2·9	3·2	2·2
								1932–33.								
Spring .	3·7	3·2	2·9	4·1	5·2	6·8	4·3	2·8	(4·5)	(2·9)	(5·6)	3·5	3·9	4·7	6·3	4·6
Summer .	4·6	3·5	3·3	4·1	4·5	5·9	4·4	3·8	4·0	4·7	4·9	6·4	5·1	6·1	6·3	5·4
Autumn .	4·0	3·7	3·2	3·7	3·1	6·2	5·5	4·5	3·6	3·5	4·2	5·7	6·5	7·9	7·3	6·1
Winter .	4·5	4·4	3·3	3·0	3·7	5·3	6·2	2·7	(4·2)	2·6	2·7	4·1	6·0	6·4	6·2	5·2
Year . .	4·3	3·5	3·2	3·9	4·2	6·0	4·9	3·8	3·8	3·9	3·9	4·7	5·9	6·4	6·4	5·3
								Combined Years.								
Spring .	2·5	2·5	2·3	2·9	3·9	5·5	3·6	1·4	(2·7)	(1·5)	(2·8)	2·7	3·5	4·5	4·6	3·3
Summer .	3·2	2·6	2·9	3·5	3·7	4·5	3·7	3·7	3·3	3·7	3·4	3·9	4·0	4·3	4·8	4·1
Autumn .	3·3	3·1	2·7	3·2	3·4	4·8	4·5	4·0	3·7	3·4	4·0	4·1	4·3	5·3	5·3	4·2
Winter .	3·2	2·9	2·4	2·1	2·9	3·7	4·5	3·1	3·7	2·7	2·7	3·0	4·2	4·7	4·7	3·7
Year . .	3·1	2·7	2·6	3·1	3·5	4·7	4·0	3·7	3·4	3·4	3·2	3·3	4·3	4·7	4·8	3·7

An examination of the abridged table for the seasons, or the complete table in Vol. II, shows that, as regards wind velocity, there are also two principal directions of maximum mean wind velocity: the directions SE. to SSE. and the directions NW. to NNW. During all months and seasons the mean velocity for these principal directions have been entered in characteristic type in both tables, but all values within the brackets are based upon a small number of observations.

If we compare the results of Table 45 with Table 43 for the combined years, it is seen that in general, for the NW. wind type, the direction of maximum wind velocity coincides with the direction of maximum wind frequency, which is the NNW. Also, that for the SE. wind type, the direction of the maximum mean wind velocity is one point veered from the direction of maximum wind frequency, which is the ESE.

It may be confirmed by a comparison of Tables 10 and 11 of Vol. II, which give the results for the individual months, that for the NW. wind type, the direction of maximum mean wind velocity in general coincides with the direction of maximum wind frequency. There are a few exceptions, but the agreement is very good for all the months of the two years. A similar comparison for the SE. wind type during 1932–33 also confirms the previous statement, that in general the direction of maximum mean wind velocity coincides with the direction of maximum frequency. The agreement, however, is not so good for the SE. wind type during the months of 1882–83. It may be stated that the maximum wind frequency during the months of this year for the SE. wind type was from the ESE., but the maximum mean wind velocity was mainly from the SE. to SSE., so that the direction of mean wind velocity was one or two points veered from the direction of maximum frequency.

8. DISTRIBUTION OF WIND VELOCITIES FROM DIFFERENT DIRECTIONS

For the purpose of determining the distribution of wind velocity from the different directions, use has been made of the analysis of the hourly values for the two years carried out in § 5.

The winds were taken from the 16 points N., NNE., etc., and the grouping for the year 1932–33 was made for winds of velocity 0 to 2·0 m/s, 2·1 to 4·0 m/s, etc.; and for the year 1882–83 for winds of velocity 0 m/s, 1 m/s, 2 m/s, etc., as entered in Captain Dawson's tables. The number of observations of 2 m/s, 4 m/s, etc., was then distributed between the adjacent groups, thus centering the groups around the velocities 1 m/s, 3 m/s, 5 m/s, etc. These velocities are the means of the velocity limits used for 1932–33. The observations for the two years can then be combined.

All the observations for each month of velocity between 0 to 2 m/s were combined together irrespective of direction, and the groups 2·1 to 4 m/s, 4·1 to 6 m/s, 6·1 to 8 m/s, etc., were later combined for each direction into groups having limits 2·1 to 6 m/s, 6·1 to 10 m/s, etc. The results for the months were combined into results for the seasons, and these have been entered in Table 46.

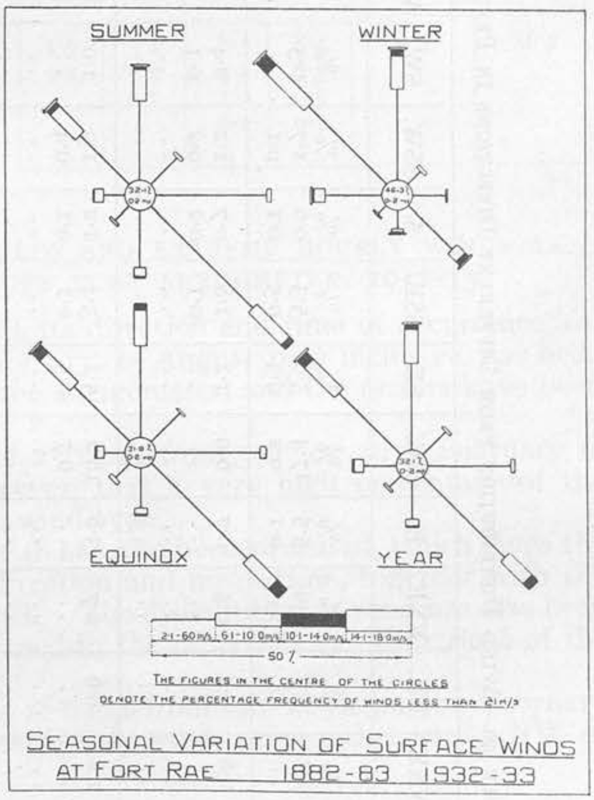


FIG. 18.

For the purpose of diagrammatic representation, the results have been further condensed by combining the two years together into 8 points instead of 16 points. The percentages given for the NNE. direction have been equally distributed between the directions N. and NE., with a similar distribution for the other directions. The results are given in Table 47, and a diagrammatic representation is given in fig. 18. The figures in the centre of the circles denote the frequency of winds from all directions with velocity less than 2·1 m/s.

TABLE 46.—WIND DISTRIBUTION FROM DIFFERENT DIRECTIONS IN PERCENTAGE FREQUENCY, 1882–83, 1932–33.

Season.	Velocity Limits.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.	N.	Indeterminate.	Velocity, 0–2 m/s.
	m/s.	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Summer 1882–83	2–6	2·1	0·7	2·9	5·5	17·4	3·0	5·3	0·6	1·7	0·5	0·6	0·2	3·3	1·1	7·5	2·6	..	41·2
	6–10	..	..	..	0·1	0·2	0·3	0·5	0·1	0·1	..	..	..	0·3	..	2·0	0·2		
Winter 1882–83	2–6	0·8	0·2	0·5	0·7	6·9	1·1	1·8	0·7	1·2	0·4	0·2	0·2	3·0	1·9	12·2	2·4	..	61·3
	6–10	..	..	..	..	..	..	0·1	0·2	0·2	0·1	..	..	0·1	0·4	2·7	0·2		
	10–14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·4	..		
	14–18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·1	..		
Equinox 1882–83	2–6	1·8	0·6	2·7	3·6	18·2	5·1	3·4	1·2	1·3	1·0	0·5	0·3	1·0	2·7	9·5	1·8	..	41·7
	6–10	..	..	..	..	0·7	0·5	0·1	0·1	0·4	..	..	0·1	0·1	0·3	1·1	0·1		
	10–14	..	..	..	..	..	..	..	..	..	..	..	0·1	..	..		..		
	14–18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·1	..		
Summer 1932–33	2·1–6	2·1	2·4	1·9	3·1	3·4	8·0	7·4	2·9	0·7	1·2	0·6	0·9	1·2	3·9	4·9	4·3	0·9	23·1
	6·1–10	0·9	..	..	0·4	0·8	7·0	1·9	0·4	0·2	0·4	0·3	1·0	1·0	3·2	3·7	2·3		
	10·1–14	..	..	..	..	..	1·2	0·1	..	..	..	..	0·2	0·1	0·7	1·0	0·1		
	14·1–18	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·1	..		
Winter 1932–33	2·1–6	2·0	1·0	0·9	0·9	1·3	4·8	1·8	0·3	0·1	0·4	0·9	7·0	3·8	6·3	6·5	4·7	0·5	31·3
	6·1–10	0·7	0·4	..	..	0·4	1·5	0·9	..	..	..	..	0·9	2·4	4·1	5·7	2·0		
	10·1–14	..	..	..	..	..	1·1	0·5	..	..	..	..	..	0·7	1·7	1·3	0·5		
	14·1–18	..	..	..	..	..	0·1	0·1	..	..	..	..	..	..	0·1	0·1	..		
	18·1–20	..	..	..	..	..	..	..	..	..	..	..	..	..	0·1	..	..		
Equinox 1932–33	2·1–6	2·3	2·9	2·2	3·4	3·2	6·2	5·1	1·0	0·8	0·8	0·8	1·7	1·6	3·4	6·0	6·1	0·3	21·9
	6·1–10	0·3	0·1	..	0·4	0·8	4·9	1·5	0·3	0·1	0·2	0·1	0·7	1·1	3·7	6·5	2·9		
	10·1–14	..	..	..	..	..	2·4	0·4	..	..	..	..	0·1	0·3	1·6	1·1	0·7		
	14·1–18	..	..	..	..	..	..	..	..	..	..	..	..	..	0·1	0·1	..		

The results confirm the statements made in preceding sections. The high wind velocities occur mainly from the S. to SE. and the NW. to N. directions. High wind velocities occur very infrequently, the percentage during all seasons never exceeding 0·1 in the limits 14 to 18 m/s.

TABLE 47.—WIND DISTRIBUTION FROM DIFFERENT DIRECTIONS IN PERCENTAGE FREQUENCY FOR THE COMBINED YEARS, 1882–83 AND 1932–33.

Season.	Velocity Limits.	NE.	E.	SE.	S.	SW.	W.	NW.	N.	Indeterminate.	Velocity, 0–2 m/s.
	m/s	%	%	%	%	%	%	%	%	%	%
Summer	2–6	3·7	10·7	13·9	5·5	1·8	1·9	6·7	7·7	0·5	32·1
	6–10	0·3	0·5	4·5	0·9	0·2	0·9	3·4	3·0		
	10–14	..	..	0·7	0·1	..	0·1	0·5	0·3		
	14–18	..	..	..	..	..	..	0·1	0·1		
Winter	2–6	1·7	3·2	5·9	1·7	1·0	5·5	10·5	8·8	0·3	46·3
	6–10	0·3	0·1	1·1	0·4	0·1	1·1	5·1	3·3		
	10–14	..	..	0·7	0·1	..	0·1	1·5	0·7		
	14–18	..	..	0·1	0·1	..	0·1	0·1	0·1		
Equinox	2–6	4·0	10·1	13·2	3·8	1·8	2·0	7·6	8·8	0·1	31·8
	6–10	0·1	0·6	3·5	0·7	0·3	0·7	4·2	3·5		
	10–14	..	..	1·3	0·1	..	0·1	1·1	0·6		
	14–18	..	..	..	..	..	..	0·1	..		
Year	2–6	3·1	8·0	11·0	3·7	1·5	3·1	8·3	8·4	0·3	36·7
	6–10	0·2	0·4	3·0	0·7	0·2	0·9	4·2	3·3		
	10–14	..	..	0·9	0·1	..	0·1	1·0	0·5		
	14–18	..	..	0·1	..	..	..	0·1	0·1		

9. HIGHEST INSTANTANEOUS WIND SPEEDS AND EXTREME HOURLY WINDS AS RECORDED BY THE DINES PRESSURE TUBE ANEMOMETER, 1932–33

The highest instantaneous wind speed, its direction and time of occurrence, for each day of the fourteen months from July 1932 to August 1933 inclusive, has been prepared from the records of the Dines tube anemometer, and the results have been entered in Table 12, Vol. II.

The highest gust recorded was one of 23·1 m/s from 340° on 1933 February 9. An examination of the table shows, however, that a very high percentage of the maximum gusts occur with a SE. or NW. wind type.

For the purpose of completion, Table 48 has also been prepared, which gives the highest hourly wind for the month, its direction and mean time, together with the maximum gusts recorded during that month. The distribution of wind has also been entered in the same form as is normally used in the *Observatories' Year Book* of the British Meteorological Office.

The maximum mean hourly wind was 18·6 m/s from 340° at 7h 30m on February 9. It is further noticed that all the highest hourly winds occur either with a NW. or SE. wind type.

10. THE EFFECT OF THE NW. AND THE SE. TYPE OF WIND UPON THE METEOROLOGICAL ELEMENTS

From the preceding sections it has been seen that the NW. and SE. type of winds are the prevailing winds at Fort Rae, and in order to determine whether these prevailing winds from practically opposed directions have different effects upon the mean values and the diurnal inequalities of the meteorological elements of pressure, temperature, wind velocity, and cloud amount, the following investigation has been undertaken for the year 1932–33.

A day of NW. wind was defined as a day during which the wind had for 18 out of 24 hours a direction lying between 236° and 34°, whereas a day of SE. wind was one during which the wind had for 18 out of 24 hours a direction lying between 56° and 214°, directions being reckoned from true N. through E. Any hour with a calm, which meant for the Dines anemograph a velocity less than 1·6 m/s, was reckoned as an adverse count. In order, however, to avoid winds from either of these directions which might be due to local effects such as the presence of land and water near the site of the station, it was considered advisable to include only those days during which the mean wind velocity of the day was greater than or equal to 4·0 m/s. In this manner it was thought that only those days during which a comparatively deep mass of air was in motion from the specified directions would be counted, and those days during which a very shallow layer of air, which might be due to local effects, would be excluded.

TABLE 48.—DISTRIBUTION OF WIND SPEED: EXTREME VELOCITIES AS RECORDED BY THE DINES TUBE ANEMOMETER, 1932–33.

Month.	Distribution of Wind Speed.						Extreme Velocities.								
	More than 17·1 m/s.	10·8 to 17·1 m/s.	5·5 to 10·7 m/s.	1·6 to 5·4 m/s.	0 to 1·5 m/s.	No Record.	Highest Hourly Wind.				Highest Gust.				
	Duration.	Duration.	Duration.	Duration.	Duration.	Duration.	Veer from N.	Speed.	Mid Time.		Speed.	Veer from N.	Date.		
	hours.	hours.	hours.	hours.	hours.	hours.	°	m/s.	day.	hr.	m/s.	°	day.	hr.	min.
1932 July	0	12	182	439	111	0	130	14·0	1	13·30	19·4	130	1	13	35
Aug.	0	25	237	323	159	0	335	15·0	18	7·30	19·7	340	18	7	55
Sept.	0	49	243	287	141	0	310	15·1	31	9·30	21·6	305	30	5	00
Oct.	0	42	253	352	97	0	325	14·7	5	10·30	19·9	325	5	11	05
Nov.	0	58	267	304	84	7	150	15·5	25	18·30	19·4	135	25	13	25
Dec.	0	12	207	286	239	0	335	15·6	16	8·30	19·9	335	16	8	40
1933 Jan.	0	14	75	398	257	0	{340 {140	} 12·6	{14 {25	0·30 5·30	} 16·3	345	13	23	55
Feb.	1	44	205	276	141	5	340	18·6	9	7·30	23·1	340	9	7	50
Mar.	0	35	173	396	140	0	345	15·4	11	7·30	21·5	345	11	7	20
Apr.	0	27	224	386	83	0	135	14·0	26	3·30	18·8	135	26	7	45
May	0	1	247	359	137	0	325	10·8	25	5·30	18·2	225	20	15	40
June	0	10	274	303	133	2	330	12·9	19	4·30	17·5	155	29	15	20
July	0	27	178	402	137	0	340	15·1	10	0·30	20·8	330	10	0	25
Aug.	0	27	257	333	127	0	330	13·2	31	23·30	17·7	325	15	16	40
Year	..	..	..	..	..	..	340	18·6	Feb. 9	7·30	23·1	340	Feb. 9	7	50

With these conditions the mean values, together with the diurnal inequalities of pressure, temperature, wind velocity, and cloud amount, have been determined for all seasons of the year from the hourly data extending from September 1932 to August 1933.

(a) *The effect upon the mean values of pressure, temperature, wind velocity, and cloud amount.*—Table 49 gives the results of the computation for the mean values of the meteorological elements during the seasons of the year. The numbers of days used in determining the mean values have also been entered in the table, and here it is noticed that the numbers of days used for determining the mean values of cloud amount are different from the numbers used in determining the mean values of the other elements. This difference is due to the fact that on some of the days used for the determination of the mean values of pressure, temperature, and wind velocity, the observation of cloud amount at 3h and 4h in the morning was not taken, and during that period an abrupt change in the cloud covering, which prevents interpolation for these hours, had occurred. Consequently, the number of days used in the determination of the mean values of cloud amount is less than or equal to the number used in determining the other mean values.

The table shows that the mean pressures during NW. and SE. winds do not differ greatly during the spring, summer, and autumn, but that there is a striking difference of 11·93 mb. during the winter, the low mean pressure of 989·78 mb. being associated with the SE. winds.

TABLE 49.—MEAN SEASONAL VALUES OF THE PRESSURE, TEMPERATURE, WIND VELOCITY, AND CLOUD AMOUNT DURING NW. AND SE. WINDS ($\bar{V} \geqslant 4{\cdot}0$ m/s).

Season.	Pressure.		Temperature.		Wind Velocity.		Cloud Amount.		No. of Days used in Press., Temp., Velocity.		No. of Days used in Cloud Amount.	
	NW.	SE.	NW.	SE.	NW.	SE.	NW.	SE.	NW.	SE.	NW.	SE.
	mb.	mb.	°C.	°C.	m/s.	m/s.	tenths.	tenths.				
Spring .	998·15	998·96	−14·45	−8·66	6·30	6·83	7·2	5·6	14	11	14	11
Summer	991·74	991·43	9·82	12·32	5·99	5·51	7·3	5·6	28	31	27	27
Autumn	992·35	990·21	1·58	3·15	6·82	5·55	6·8	8·3	18	12	10	5
Winter	1001·71	989·78	−23·90	−23·11	6·84	6·32	5·7	6·4	37	10	37	10

The mean temperature is lower during the NW. winds than during the SE. winds for all seasons of the year, the difference being greatest during the spring and least during the winter.

The mean velocity of winds from the NW. is greater than the mean velocity from the SE. except during the spring, when the SE. winds are stronger. This statement, however, applies to days when the mean daily wind velocity is greater than or equal to 4·0 m/s.

The NW. winds are associated with a greater cloud amount than the SE. winds during the spring and summer, but in the autumn and winter the SE. winds are associated with the greater cloud amount.

(b) *The effect upon the diurnal inequalities of temperature, pressure, wind velocity, and cloud amount.*—The same days used for determining the mean values of the meteorological elements have been used in determining the diurnal inequalities, but the direct values of the inequalities have been smoothed by means of the formula $4\bar{b} = a + 2b + c$.

The smoothed values of the inequalities of pressure, temperature, wind velocity, and cloud amount during the seasons for days of NW. and SE. winds have been entered in Table 13, Vol. II.

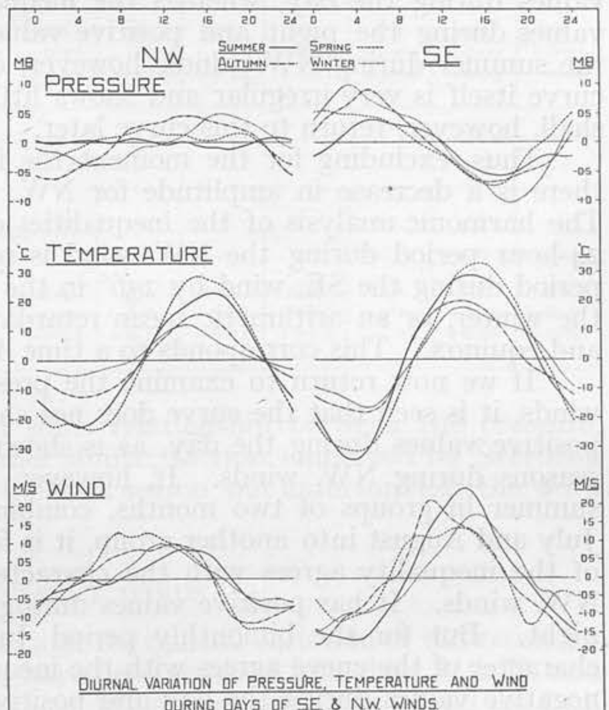


FIG. 19.

Apart from the inequalities of cloud amount, these values of the diurnal inequalities have been plotted against time in fig. 19, and the resulting points have been joined by smooth curves.

The results show that the amplitudes of the diurnal variation of pressure, temperature, wind velocity, and cloud amount are greater during the four seasons with the SE. type than during the corresponding seasons with the NW. type. The meteorological elements which do not conform to the above statement are the wind velocity and the cloud amount during the spring, where the amplitudes for both the SE. and the NW. types have nearly identical values. The values of the amplitudes of the diurnal inequalities of the meteorological elements for the different seasons are given in Table 50.

TABLE 50.—AMPLITUDES OF THE DIURNAL VARIATIONS OF PRESSURE, TEMPERATURE, WIND VELOCITY, AND CLOUD AMOUNT DURING NW. AND SE. WINDS ($\bar{V} \geqslant 4{\cdot}0$ m/s).

Season.	Pressure (mb.).		Temperature (°C.).		Wind (m/s).		Cloud (tenths).	
	NW.	SE.	NW.	SE.	NW.	SE.	NW.	SE.
Spring .	0·60	1·26	5·21	6·40	2·69	2·64	2·61	2·61
Summer .	0·19	0·97	4·52	6·24	1·61	4·10	1·23	2·01
Autumn .	1·06	1·59	2·79	3·77	2·13	3·90	2·14	3·43
Winter .	0·88	2·01	1·70	3·37	1·58	3·12	1·16	4·55

Another striking feature of the inequalities, which is more apparent from the curves than from the tables, is the different character of the pressure inequalities during the SE. and NW. winds for all seasons. The inequalities of pressure for the SE. type are characterised by positive values during the night and negative values during the day, whereas the inequalities for the NW. type have negative values during the night and positive values during the day. The inequalities for the summer during NW. winds, however, do not show this distinct difference; the curve itself is very irregular and shows little change throughout the 24 hours. We shall, however, return to this curve later.

Thus, excluding for the moment the inequalities of pressure for the summer, there is a decrease in amplitude for NW. winds and a complete change of phase. The harmonic analysis of the inequalities of pressure shows that the phase of the 24-hour period during the NW. wind is retarded upon the phase of the 24-hour period during the SE. wind by 136° in the spring, 137° in the autumn, and 185° in the winter, or an arithmetic mean retardation of 161° for the two periods, winter and equinox. This corresponds to a time difference of 10·7 hours.

If we now return to examine the pressure curve for the summer during NW. winds, it is seen that the curve does not show negative values during the night and positive values during the day, as is shown by the inequalities for the three other seasons during NW. winds. If, however, we examine the inequalities during the summer in groups of two months, combining May and June into one group and July and August into another group, it is found that for May and June the character of the inequality agrees with the character of those for the other seasons during NW. winds. It has positive values during the day and negative values during the night. But for the bimonthly period July, August, during the NW. winds the character of the curve agrees with the inequalities of pressure for SE. winds, having negative values during the day and positive values during the night. This change of character during NW. winds for the bimonthly period July, August is quite a striking feature, and no explanations can be offered.

The summer bimonthly inequalities of pressure during NW. winds are given in Table 51.

There is no decided change in the phases for the temperature during the NW. and SE. winds. There appears, however, to be a slight advance of phase in the wind velocity with the NW. compared with the SE. wind, but the phase difference is small.

The foregoing results would seem to show that the NW. and SE. winds are characterised by

(i) Greater amplitudes of the diurnal variation of pressure, temperature, wind velocity, and cloud amount during the SE. than during the NW. wind.

(ii) A retardation of pressure phase during the NW. winds corresponding to a time difference of from 9 to 12 hours; the only period not conforming to the above being the bimonthly period July and August, which has a variation with a phase similar to that for the SE. wind.

(iii) A phase of temperature which is independent of the wind direction.

(iv) A phase of wind velocity which is slightly more advanced with the NW. wind than with the SE. wind.

(c) *Harmonic analysis of the inequalities during NW. and SE. winds.*—The harmonic analysis of the inequalities of pressure, temperature, and wind velocity given in the foregoing paragraph has been carried out, and the computed coefficients are given in Table 52 (p. 76), but no new results emerge from the analysis.

TABLE 51.—BIMONTHLY DIURNAL INEQUALITIES OF PRESSURE FOR THE SUMMER DURING NW. WINDS ($\bar{V} \geqslant 4{\cdot}0$ m/s).

The departures from the mean are corrected for non-cyclic change.

Period.	Z.M.T.											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
May, June	−0·06	−0·15	−0·13	−0·09	−0·09	−0·15	−0·13	−0·15	+0·04	+0·03	0·00	+0·04
July, August	+0·01	+0·09	+0·12	+0·13	+0·19	+0·13	+0·12	+0·12	+0·21	+0·08	−0·03	−0·09

Period.	Z.M.T.											
	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
May, June	+0·10	+0·24	+0·12	+0·13	+0·04	−0·05	−0·09	+0·06	+0·09	+0·14	+0·10	−0·45
July, August	−0·12	−0·10	−0·19	−0·33	−0·16	−0·18	−0·17	−0·04	+0·02	+0·03	+0·08	+0·08

An attempt has been made to find some relationship between the pressure, temperature, and wind velocity in a manner similar to that employed by Sverdrup when discussing their relationship during the dark season, but unfortunately the work has led to no definite results.

II. THE RESULTANT WINDS

In order to determine the hourly values and the diurnal variation of the resultant winds, all the hourly values for both years have been resolved into their S. to N. and E. to W. components. Thus, by an algebraic addition, for each month and for each hour of the day the mean N. component and the mean E. component is determined. These values will be called the unadjusted means.

But in order to remove the effect of the yearly variation, a non-cyclic correction has been applied to the unadjusted means during each month for the two components. These values will be called the adjusted means.

The departure of the adjusted means from the mean of the month gives the diurnal inequalities for each component.

(a) *Hourly resultant wind speed and direction.*—The hourly resultant wind speeds and directions computed from the unadjusted means of the month for the separate years have been entered in Table 14, Vol. II.

It may be stated that during the year 1882–83 the hourly resultant winds for the winter months, November, December, January, and February, were from the NW. to NNE., and for the remainder of the year the winds were from an E by N. to SE. direction.

TABLE 52.—HARMONIC COEFFICIENTS OF THE DIURNAL INEQUALITY OF PRESSURE, TEMPERATURE, AND WIND VELOCITY DURING NW. AND SE. WINDS AT FORT RAE, 1932–33.

Values of c_n, a_n in the series $c_n \sin(15nt + a_n)$, t being Zonal Mean Time reckoned in hours from midnight.

	Type.	Season.	c_1.	a_1.	c_2.	a_2.	c_3.	a_3.	c_4.	a_4.
Pressure.			mb.	°	mb.	°	mb.	°	mb.	°
	NW.	Spring	0·20	261	0·11	235	0·06	279	0·03	330
		Summer	0·04	25	0·05	133	0·03	178	0·03	238
		Autumn	0·51	238	0·10	215	0·03	257	0·04	279
		Winter	0·39	185	0·05	271	0·06	4	0·03	220
	SE.	Spring	0·60	37	0·12	119	0·03	203	0·03	31
		Summer	0·44	356	0·07	191	0·07	247	0·03	206
		Autumn	0·74	15	0·08	312	0·03	267	0·04	77
		Winter	0·89	12	0·21	52	0·05	19	0·04	239
Temperature.			°C.	°	°C.	°	°C.	°	°C.	°
	NW.	Spring	2·71	214	0·25	348	0·15	277	0·07	262
		Summer	2·24	214	0·06	284	0·11	8	0·04	57
		Autumn	1·31	215	0·22	25	0·06	107	0·02	213
		Winter	0·75	232	0·19	42	0·09	195	0·03	29
	SE.	Spring	3·22	221	0·07	34	0·04	106	0·07	287
		Summer	3·05	229	0·29	139	0·20	65	0·07	47
		Autumn	1·88	237	0·40	85	0·11	19	0·11	227
		Winter	1·62	219	0·21	96	0·14	283	0·09	280
Wind Velocity.			m/s.	°	m/s.	°	m/s.	°	m/s.	°
	NW.	Spring	1·38	301	0·12	343	0·10	247	0·04	293
		Summer	0·67	267	0·31	360	0·07	288	0·03	209
		Autumn	1·02	301	0·31	32	0·10	202	0·09	282
		Winter	0·72	271	0·17	84	0·10	285	0·05	138
	SE.	Spring	1·20	267	0·36	94	0·13	106	0·11	187
		Summer	1·91	242	0·38	64	0·21	250	0·08	323
		Autumn	1·66	268	0·12	115	0·31	289	0·18	215
		Winter	1·36	231	0·28	348	0·15	251	0·10	241

The NW. resultant winds persisted for a longer period during 1932–33; the months from August 1932 to March 1933 inclusive, together with June 1933, have resultant winds mainly from the WNW. to N. The four months, April, May, August 1933, and July 1932, show resultant winds from the ENE. to SE. directions. The month of July 1933 is the only month which shows an extremely irregular direction, the resultant wind veering from NW. in the morning back to NW. by midnight, through all points of the compass.

(b) *Seasonal and diurnal variation of the resultant wind.*—The unadjusted mean values of the N. and E. components of wind velocity have been combined into the four seasons, spring, summer, autumn, and winter, and adjusted mean values computed. These adjusted seasonal mean values have been entered in Table 15, Vol. II, and the results have been represented in fig. 20 (*a*), (*b*) for the two years separately. In each diagram it is to be noticed that the resultant wind blows outwards from the origin, and that the hourly values during the year 1932–33 are the means of the hour centred at the half-hour, whereas for the year 1882–83 they are the values at the exact hours. There is also a difference in the scale value in the two diagrams.

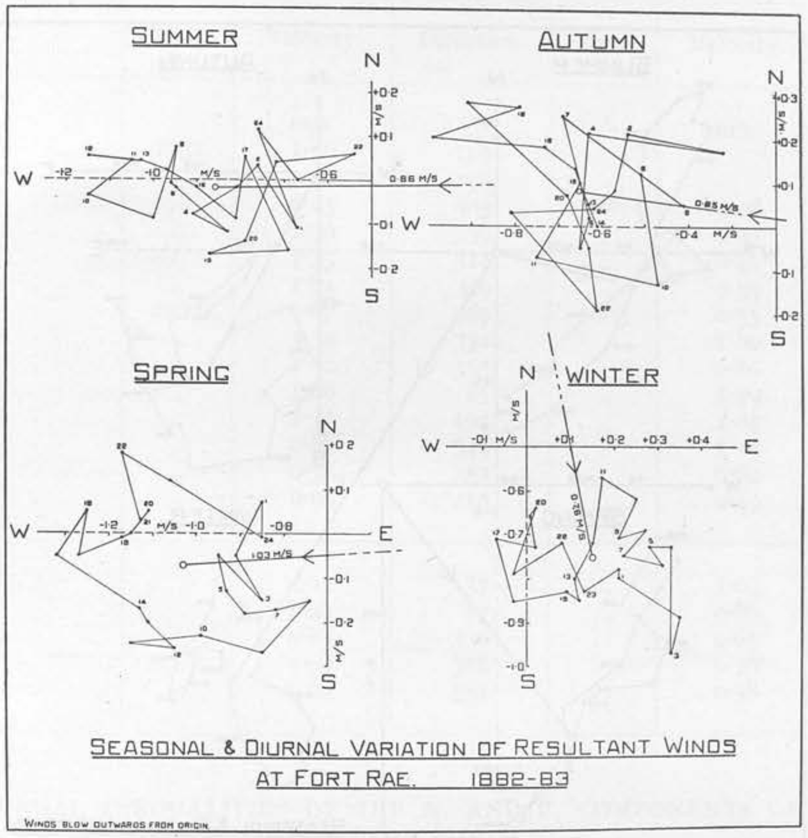


FIG. 20 (*a*).

The final resultant wind for each season has also been represented in the diagrams by a thick line drawn from the origin.

A comparison of the diagrams for the two years shows that, whereas the curves for the hourly resultant winds during 1932–33 are fairly regular, those for 1882–83 are extremely irregular. These irregularities of the curves are partly due, no doubt, to the method of estimating the wind force in the Beaufort scale, and the direction to the 16 points. The results for that year cannot be as accurate as those obtained from the Dines anemograph.

During the summer 1932–33 the rotation of the resultant wind is on the whole clockwise, the direction of the resultant wind turning to the right during the morning hours before noon and to the left during the afternoon and evening hours. The most rapid turning to the right occurs from 4h 30m to 11h 30m, and to the left from 14h 30m to 1h 30m, except for a few hours from 17h 30m to 19h 30m, when the direction remains fairly steady. The average resultant velocities are generally greater during the morning than during the afternoon or evening hours.

The results for the summer 1882–83 are very irregular, and the change in direction is only small during the 24 hours. The average resultant velocities are also greater during the morning than the evening hours.

The rotation during the autumn 1932–33 is again clockwise, the most rapid turning to the right occurring from 3h 30m to 8h 30m, and to the left from 13h 30m to around midnight. The average resultant velocities are greatest during the early morning hours and least during the late afternoon.

The results for the autumn 1882–83 are extremely irregular, and it is doubtful whether any general results can be deduced. They seem to show an average resultant wind greatest during the evening hours and least during the morning hours. This result is different from that obtained for autumn 1932–33.

The rotation of the resultant wind during the winter 1932–33 is clockwise, large

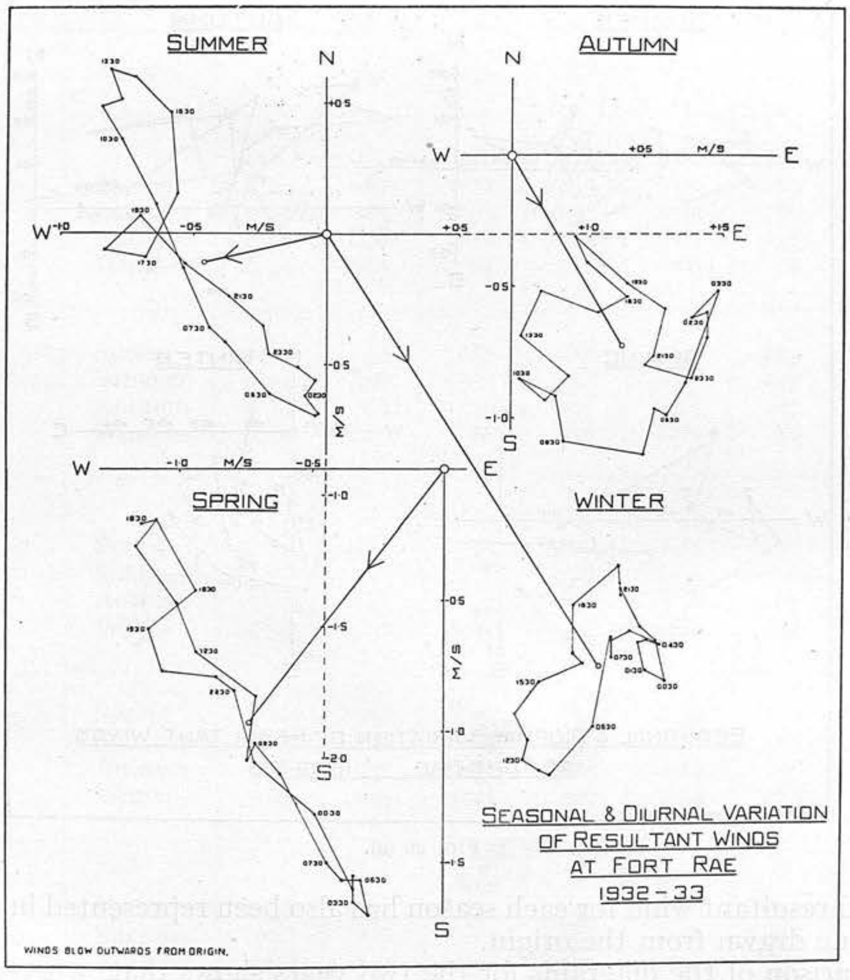


FIG. 20 (*b*).

values occurring during the morning hours and small values during the evening. The change in direction during the 24 hours is small. The most rapid turning to the right occurs from 4h 30m to 10h 30m, and to the left from 12h 30m to 20h 30m. For 1882–83 the rotation is anticlockwise from 23h to 13h and clockwise from 13h to 23h. The greatest resultant velocities occur during the early hours of the morning.

For the year 1932–33 the spring has a well-defined curve, showing the most rapid turning to the right from 4h 30m to 14h 30m and to the left from 17h 30m to 1h 30m. The greatest resultant winds occur during the early hours of the morning and the least values during the evening.

During the spring 1882–83 the rotation is clockwise, with the least values of the wind during the early hours of the morning and the greatest values during the afternoon and evening hours.

(c) *Monthly and seasonal resultant winds.*—Use has been made of the analysis of the hourly values of wind velocity into their components, in order to determine the resultant wind for the different months of the two years. The results have been entered in Table 53.

TABLE 53.—MONTHLY AND SEASONAL RESULTANT WINDS, 1882–83, 1932–33.

Month or Season.	1932–33.			1882–83.		
	Year.	Velocity.	Direction.	Year.	Velocity.	Direction.
		m/s.	°		m/s.	°
July	1932	1·59	110			
August	,,	0·96	293			
September	,,	0·45	303	1882	0·28	67
October	,,	1·30	339	,,	1·07	105
November	,,	2·33	324	,,	0·42	347
December	,,	1·64	340	,,	0·59	3
January	1933	0·67	289	1883	0·55	10
February	,,	3·34	332	,,	1·60	335
March	,,	1·80	353	,,	0·80	74
April	,,	1·68	85	,,	1·29	94
May	,,	1·30	102	,,	1·03	92
June	,,	0·86	349	,,	1·19	78
July	,,	0·31	352	,,	0·82	109
August	,,	0·99	115	,,	0·49	73
Spring	..	1·21	37	..	1·03	86
Summer	..	0·47	77	..	0·86	89
Autumn	..	0·83	330	..	0·65	97
Winter	..	1·94	328	..	0·76	348
Year	..	0·88	351	..	0·58	64

12. DIURNAL INEQUALITIES OF THE N. AND E. COMPONENTS OF THE RESULTANT WINDS

(a) *All days.*—The diurnal inequalities of the N. and E. components of the resultant winds have been determined from the adjusted means for each month and season of the two years. The results have been entered in Table 16, Vol. II, and the inequalities for the seasons have been represented in fig. 21 (*a*), (*b*), under the title "All Days."

If the diurnal variation of the E. component be first considered, it is seen that for the two years during all seasons the inequalities present similarities. In general, the inequalities show positive values during the night and early morning hours and negative values during the day. The amplitude of the variation was greater in 1932–33 than in 1882–83.

The variation in the N. components do not show such a close similarity between the two years. The variation in 1882–83 was exceedingly small and irregular. The variations during the summer and equinox of 1932–33 show certain similarities. They have positive inequalities during the day and negative inequalities during the night. The inequality for the winter of 1932–33 shows a similar type of curve, except that the maximum is retarded to the evening and the minimum to about noon.

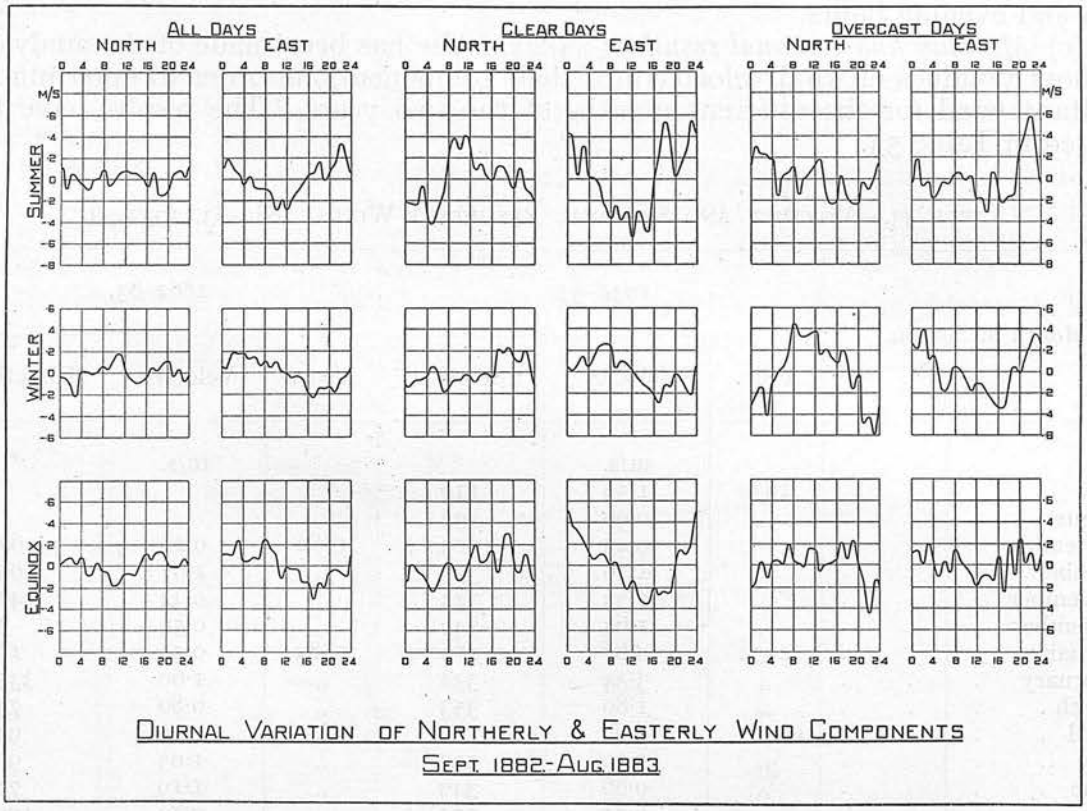


Fig. 21 (*a*).

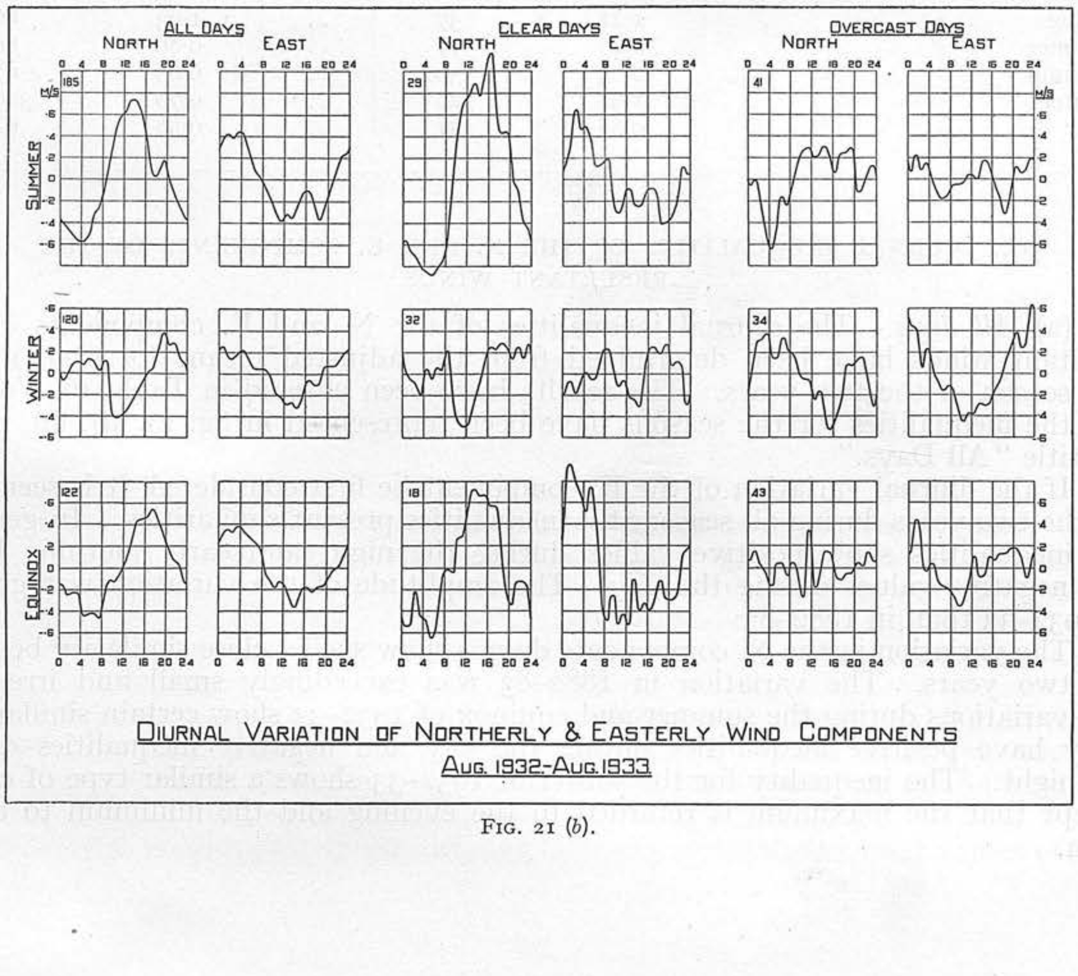


Fig. 21 (*b*).

(b) *Clear days and overcast days.*—The diurnal inequalities of the N. and E. components of the resultant winds have also been determined for the seasons for all days during which the mean cloud amount was less than or equal to three-tenths, and for all days during which the mean cloud amount was greater than or equal to eight-tenths. The inequalities during these clear and overcast days have been entered in Table 17, Vol. II, and the values have also been represented in fig. 21 (*a*), (*b*), for the respective years, under the titles "Clear Days" and "Overcast Days." The inequalities are, however, too irregular for any general statements to be made.

PART IV.—UPPER WINDS: RESULTS OF PILOT BALLOON ASCENTS AND NEPHOSCOPE OBSERVATIONS

I. GENERAL REMARKS

About four hundred pilot balloons were taken to Fort Rae for determining the velocity and direction of the wind at different heights in the atmosphere during the year 1932–33. No ascents had been made during the First Polar Year Expedition, so that the discussion of the upper winds will be based entirely upon the results of these ascents, augmented by the results of the nephoscope observations.

The hydrogen used for the inflation of the balloons was made at Fort Rae from a mixture of silicol and concentrated caustic soda, the gas, as it was liberated from the generator, being stored in large rubbered fabric bags, from which, by means of a foot bellows, the pilot balloons were inflated as occasion needed.

Altogether 385 pilot balloon ascents were made, and of these 373 ascents were made from 1932 August 1 to 1933 August 31, the remaining 12 ascents being made during the last few days of July 1932. The following discussion is based upon the 373 ascents, but the period covers two Augusts, so that the results for these two months have been combined in order to obtain a representative August whenever the month has entered into the summer season or year.

The balloons were released at or near the auroral enclosure, and the theodolite was placed either in or just outside this enclosure. The fixed mark for the azimuth was taken from the flagstaff on the quarters of the Royal Canadian Mounted Police, and it was sufficiently far away to avoid small errors in the azimuth arising by shifting the theodolite a few feet from the outside to the inside of the auroral enclosure.

Normally the balloons were inflated with hydrogen to rise vertically at a rate of 500 ft./min., but it was found that, with the hydrogen generated, the balloons rarely acquired this rate of ascent. In practically all ascents, however, a tail was used, so that the rate of ascent of the balloon was immaterial for the purpose of computing the wind velocities at various heights. Ascents without a tail were only made when there was no opportunity of obtaining observations to a height of more than 1000 to 2000 ft., owing to an overcast sky, or on occasions when the tail unfortunately broke during the release of the balloon.

Observations of the position of the balloon in azimuth and elevation, together with the graticule readings of the tail, were taken every minute, and the method of computation of the velocity and direction is given in detail in the *Computer's Handbook*.

The values of the velocity and direction were grouped in layers around the mean heights of 1000, 2000, etc. to 6000 ft., 8000, 10,000, etc. to 20,000 ft., and mean values of the velocity and direction in each layer determined. Thus the layer with a mean height of 1000 ft. would extend from 750 to 1250 ft.; a mean height of 2000 ft. from 1750 to 2250 ft., etc.; but a mean height of 8000 ft. would extend from 7500 to 8500 ft., and a mean height of 10,000 ft. would extend from 9500 to 10,500 ft., etc.

2. MONTHLY AND SEASONAL MEAN WIND VELOCITIES AT DIFFERENT HEIGHTS

The mean velocities obtained from the ascents for the months and the seasons have been entered in Table 18, Vol. II, in which the other columns denote the number of observations determining the mean velocity at that height. An abstract from the table for the seasons and the year has been entered in Table 54.

It is noticed that there are two values given for the mean wind velocity at the surface. The lower surface values correspond to the mean velocity as obtained from the hourly values of the Dines anemograph, whereas the upper corresponds to mean values as obtained from the Dines anemograph immediately before each ascent.

TABLE 54.—SEASONAL MEAN WIND VELOCITIES IN THE UPPER AIR.

Height.	Winter.		Summer.		Equinox.		Year.	
feet.	m/s.	No.	m/s.	No.	m/s.	No.	m/s.	No.
20,000	20·5	2	7·0	17	16·0	9	10·9	28
18,000	19·0	3	6·5	31	12·8	10	8·8	44
16,000	18·5	2	6·9	40	11·3	14	8·4	56
14,000	14·0	2	7·4	52	10·2	20	8·4	74
12,000	13·6	8	6·7	68	10·6	29	8·3	105
10,000	11·1	14	6·4	86	10·4	45	8·1	145
8,000	11·5	27	6·9	102	9·8	64	8·5	193
6,000	9·8	41	6·9	113	9·0	76	8·1	230
5,000	8·8	51	6·6	124	8·5	80	7·7	255
4,000	8·2	56	6·4	132	8·5	87	7·4	275
3,000	7·6	56	6·5	134	8·7	104	7·5	294
2,000	7·3	54	6·2	138	8·0	111	7·1	303
1,000	6·7	54	5·6	142	7·3	116	6·4	312
Surface . . .	3·3	65	4·6	143	5·1	126	4·5	334
Surface . . .	4·2	. .	4·4	. .	4·7	. .	4·5	. .

The number of ascents made during May, June, July, August 1933 and August 1932 was 187, but in combining these months into a representative summer season the two Augusts have been meaned at the various heights, so that the total number of observations for the summer was reduced to 143. Actually the results for the summer are based upon 187 ascents. A similar effect arises with the total observations for the year, the effective number of observations being taken as 334, though the result is based upon 373 balloon ascents.

The agreement of the two sets of surface values is on the whole good, not only for the seasons and year but also for the individual months, except for the months of September and November 1932 and August 1933, which show differences in the mean velocity of 1·3, 1·6, and 1·0 m/s respectively.

The values of the mean wind velocity for the seasons and the year have been plotted against height in fig. 22, and the points have been joined by smooth lines.

The most rapid increase of wind velocity during all months of the year occurs in the lowest layer between the surface and 1000 ft. The winter shows a mean increase with height of 3·4 m/s, the equinox of 2·2 m/s, and the summer of 1·0 m/s in the first 1000 ft. The rapid increase in velocity persists up to 3000 ft., after which the rate of increase decreases, except during the winter months when a steady increase persists up to the highest heights attained of 20,000 ft. For greater heights than

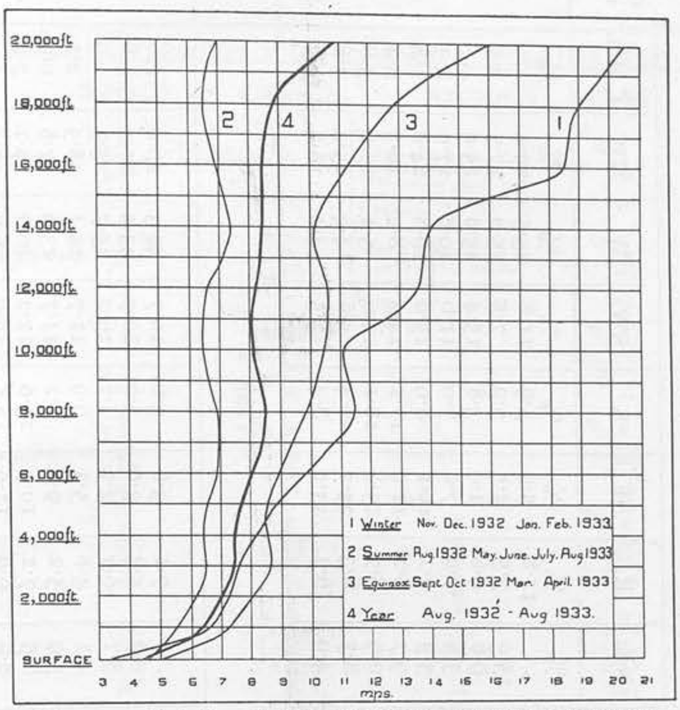


Fig. 22.—Variation of wind with height during the seasons at Fort Rae, 1932–33.

3000 ft. the velocity during the equinox increases slowly up to 14,000 ft., and then increases rapidly at least up to 20,000 ft. During the summer, however, the velocity above 3000 ft. remains fairly steady around 7 m/s up to the highest heights attained of 20,000 ft.

3. FREQUENCY OF WIND FROM VARIOUS DIRECTIONS IN THE UPPER ATMOSPHERE

(a) *From pilot balloon ascents.*—All the pilot balloon ascents have been analysed to determine the frequency of winds from the 8 points, N., NE., etc., at the heights given in the preceding section. A wind is taken as a N. wind if it blows from the interval 338° to 22°, as a NE. wind if it blows from the interval 23° to 67°, etc., all values being reckoned from true N. through E.

In addition, within each direction, the winds were classified according to their velocity, the velocity groups taken being 2 to 7 m/s, 8 to 14 m/s, 15 to 21 m/s, and greater than or equal to 22 m/s, any velocity less than 2 m/s being considered as calm.

The results of the months were combined into seasons, and the values of the percentage frequency for these seasons from the different directions have been entered in Table 55.

The values given in the table have been represented diagrammatically in fig. 23, which gives in addition the distribution of winds according to their velocity from these directions.

In fig. 23 the wind roses drawn for the surface frequencies are those corresponding to the observations of wind taken immediately before the pilot balloon ascents. If we compare these surface wind roses with those given in fig. 18, which represent the distribution of surface wind as determined from the hourly values of two years'

TABLE 55.—PERCENTAGE FREQUENCY OF WIND FROM DIFFERENT DIRECTIONS IN THE UPPER AIR AT FORT RAE, 1932–33.

Height in Feet.	Winter.									Summer.									Height in Kilo-metres.
	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
20,000	..	..	..	..	..	..	50·0	50·0	..	11·8	..	11·8	5·9	5·9	11·8	23·5	29·4	..	6
16,000	..	..	..	..	..	50·0	..	50·0	..	7·5	15·0	7·5	2·5	5·0	7·5	35·0	17·5	2·5	5
14,000	..	..	..	..	..	..	..	100·0	..	9·6	9·6	9·6	1·9	3·8	15·4	25·0	25·0	..	4
10,000	7·1	..	..	..	..	..	42·9	50·0	..	13·9	3·5	7·0	7·0	7·0	11·6	19·8	27·9	2·3	3
6,000	17·1	..	..	2·4	..	4·9	31·7	43·9	..	9·7	5·3	7·1	10·6	8·9	15·0	16·8	24·8	1·8	2
3,000	23·2	5·4	3·6	9·0	7·1	5·4	21·4	25·0	..	11·9	9·7	8·2	11·9	17·1	14·2	8·2	16·3	2·2	1
2,000	20·4	5·6	5·6	5·6	11·1	7·4	11·1	31·5	1·9	13·0	10·9	8·7	13·8	18·1	13·0	5·1	11·6	5·8	
1,000	18·5	9·3	3·7	11·1	11·1	3·7	7·4	31·5	3·7	9·9	8·5	6·3	23·2	20·4	5·6	4·9	15·4	5·6	
Surface	18·5	4·6	..	12·3	1·5	..	9·2	15·4	38·5	7·7	4·9	6·3	33·6	8·4	3·5	4·2	16·8	14·7	Surface
	Equinox.									Year.									
20,000	..	..	..	..	..	11·1	66·7	22·2	..	7·1	..	7·1	3·6	3·6	10·7	39·3	28·6	..	6
16,000	14·3	..	..	7·1	..	14·3	35·7	28·6	..	8·9	10·7	5·4	3·6	3·6	10·7	33·9	21·4	1·8	5
14,000	20·0	5·0	..	5·0	..	20·0	30·0	20·0	..	12·1	8·1	6·7	2·7	2·7	16·2	25·7	25·7	..	4
10,000	11·1	6·7	2·2	4·4	8·9	15·5	26·7	22·2	2·2	12·4	4·1	4·8	5·5	6·9	11·7	24·1	28·3	2·1	3
6,000	13·2	3·9	5·3	10·5	2·6	10·5	30·3	23·7	..	12·2	3·9	5·2	9·1	5·2	11·7	23·9	27·8	0·9	2
3,000	9·6	8·7	7·7	10·6	18·3	13·5	6·7	22·1	2·9	13·3	8·5	7·1	10·9	15·6	12·2	10·2	20·1	2·0	1
2,000	15·3	8·1	5·4	12·6	22·5	9·9	6·3	17·1	2·7	15·2	8·9	6·9	11·9	18·5	10·9	6·6	17·2	4·0	
1,000	14·7	6·0	10·3	26·7	8·6	6·0	6·0	19·0	2·6	13·1	7·7	7·4	22·4	14·5	5·4	5·8	19·5	4·2	
Surface	15·9	4·8	4·0	31·0	7·1	1·6	3·2	19·9	12·6	12·9	4·8	4·2	28·5	6·6	2·1	4·8	17·7	18·6	Surface

observations, the agreement is comparatively good. If, however, we compare the surface wind frequencies from observations taken immediately before the upper air ascent with those obtained from the hourly values of wind taken in the same

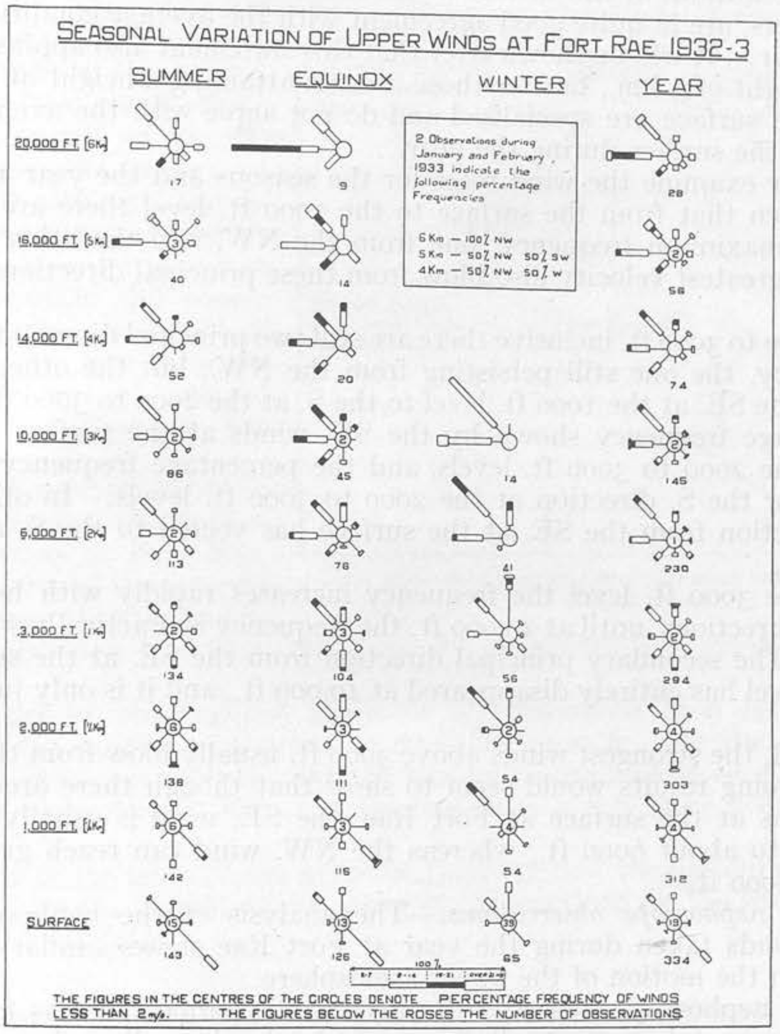


FIG. 23.

year, 1932–33, the comparison is still better. The actual figures are given in Table 56.

TABLE 56.—COMPARISON OF PERCENTAGE SURFACE WIND FREQUENCIES FROM HOURLY VALUES AND FROM VALUES AT TIMES OF BALLOON ASCENTS, 1932–33.

Season.		NE.	E.	SE.	S.	SW.	W.	NW.	N.	Calm.	Indeterminate.
		%	%	%	%	%	%	%	%	%	%
Summer .	Hourly values.	4·9	6·5	23·0	8·4	2·5	3·7	13·8	13·1	23·1	0·9
	P.B. ascents.	4·9	6·3	33·6	8·4	3·5	4·2	16·8	7·7	14·7	
Winter .	Hourly values.	3·2	2·2	9·9	2·1	0·9	11·8	22·3	15·5	31·3	0·5
	P.B. ascents.	4·6	0·0	12·3	1·5	0·0	9·2	15·4	18·5	38·5	
Equinox .	Hourly values.	5·4	6·9	19·0	5·3	1·9	4·4	17·2	17·8	21·9	0·3
	P.B. ascents.	4·8	4·0	31·0	7·1	1·6	3·2	19·9	15·9	12·7	
Year .	Hourly values.	4·5	5·2	17·3	5·3	1·8	10·0	17·8	15·5	25·4	0·6
	P.B. ascents.	4·8	4·2	28·5	6·6	2·1	4·8	17·7	12·9	18·6	

When it is considered that the surface wind frequencies at the times of ascent are based on 373 observations for the whole year, the agreement between the surface frequencies from hourly values shown in the above table is quite good. Consequently, the average conditions at the surface at the times of the upper air ascents, at least in the lower layers, are in quite good agreement with the average conditions as a whole during the year. It will be shown later that this statement also applies to all ascents reaching a height of 5 km., but for those ascents attaining a height of 6 km. the conditions at the surface are specialised and do not agree with the average conditions as a whole at the surface during the year.

If we now examine the wind roses for the seasons and the year at the different levels, it is seen that from the surface to the 1000 ft. level there are two principal directions of maximum frequency, one from the NW. and the other from the SE. The winds of greatest velocity also blow from these principal directions of maximum frequency.

From 2000 to 3000 ft. inclusive there are still two principal directions of maximum wind frequency, the one still persisting from the NW., but the other direction has veered from the SE. at the 1000 ft. level to the S. at the 2000 to 3000 ft. levels. The large percentage frequency shown by the SE. winds at the surface shows a large decrease at the 2000 to 3000 ft. levels, and the percentage frequency has increased appreciably for the S. direction at the 2000 to 3000 ft. levels. In other words, the principal direction from the SE. at the surface has veered to the S. at the 2000 to 3000 ft. levels.

Above the 3000 ft. level the frequency increases rapidly with height from the NW. and W. directions, until at 20,000 ft. the frequency is practically wholly from the NW. or W. The secondary principal direction from the SE. at the surface or S. at the 3000 ft. level has entirely disappeared at 10,000 ft., and it is only just appreciable at 6000 ft.

In general, the strongest winds above 3000 ft. usually blow from the NW. or W.

The foregoing results would seem to show that though there are two principal wind directions at the surface at Fort Rae, the SE. wind is usually shallow, only extending up to about 6000 ft., whereas the NW. wind can reach great heights at least up to 20,000 ft.

(b) *From nephoscope observations.*—The analysis of the nephoscope observations upon clouds taken during the year at Fort Rae shows similar results to the foregoing upon the motion of the upper atmosphere.

A Besson nephoscope was used throughout the period, and, as far as possible, observations were taken upon all types of clouds that allowed accurate timing across the prongs of the nephoscope. The cloud heights varied from the low Stcu at about 1000 ft. to the high Ci or Cicu clouds, but for the purpose of the analysis all clouds in the regions below 3500 ft. and from 3500 to 7000 ft. have been grouped into two groups of low cloud. A third group consisted of such medium clouds as Acu and Ast, and the fourth group of high clouds such as Ci and Cicu. The heights of the clouds up to 7000 ft. have been obtained either as an estimate at the time of making the nephoscope observation or by a pilot balloon ascent near the time of observation, unless a decided change had taken place in the cloud height after or before the balloon ascent.

Details of the method for determining the angular velocity of cloud movements from the Besson nephoscope are given in the *Observer's Handbook*, 1934. In order to determine the velocity of the cloud from its angular velocity, however, mean heights have been used for all the cloud groups. The mean heights used were 600 m. for the group of clouds below 3500 ft.; 1500 m. for clouds between 3500 and 7000 ft.; 3500 m. for the medium type of clouds such as Acu and Ast, and 6500 m. for the high type of cloud of the Ci variety. In the first group no low cloud was taken into consideration when its height was less than 500 ft.

In the reduction of the data, however, there is another factor which has to be brought into consideration. Simpson * states, when discussing the motion of the upper atmosphere in the Antarctic, that "The motion of Erebus smoke and of the clouds could only be observed when they were visible. It often happened that the motion could be recorded every time observations were made on one day and only once or twice on another day. If during the whole of the first day the motion remained constantly from, say, the N., and on the second day constantly from the S., there would be six entries of the N. motion and only one or two of the S. motion, although the S. motion continued just as long as the N. motion. In order to reduce as much as possible this source of error, whenever a sequence of the same direction was recorded on any one day it was only entered once in the reduction of the data."

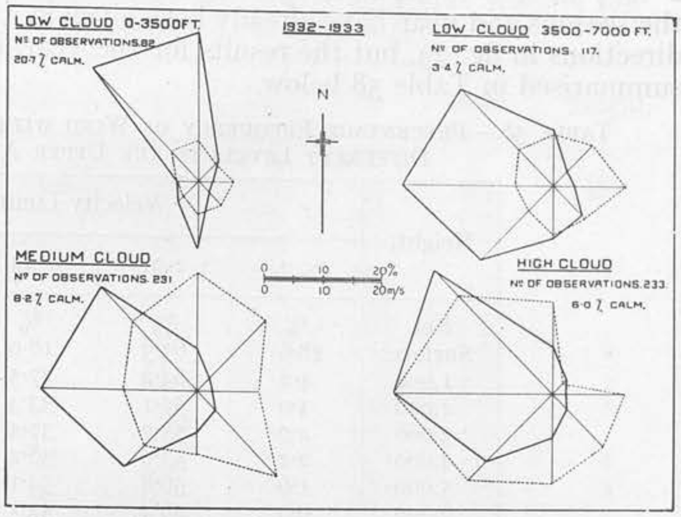


FIG. 24.—Percentage frequency and mean velocity of winds at different levels.

The same procedure has been adopted in reducing the nephoscope observations at Fort Rae, and the mean value of the velocity from the sequence of observations of the same direction has been taken as the representative velocity from that direction.

The number of observations available for discussion then becomes 663, of which 82 give the motion of the low cloud below 3500 ft., 117 the motion of the cloud between 3500 and 7000 ft., 231 the motion of the middle cloud, and 233 the motion of the high cloud. All velocities less than 2 m/s have been reckoned as calm.

The results of the analysis are given in Table 57, and the percentage frequencies are represented for the various directions in fig. 24, enclosed by the irregular octagon with the continuous sides.

TABLE 57.—PERCENTAGE FREQUENCY OF WIND FROM DIFFERENT DIRECTIONS AS OBTAINED FROM NEPHOSCOPE OBSERVATIONS, 1932–33.

Height.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	No.
	%	%	%	%	%	%	%	%	%	
< 3500 feet . . .	24·4	4·9	2·4	2·4	11·0	4·9	3·7	25·6	20·7	82
3500–7000 feet	9·4	3·4	3·4	6·8	8·5	17·1	25·6	22·2	3·4	117
Medium cloud . . .	6·9	3·0	2·6	4·3	6·9	17·7	26·8	23·4	8·2	231
High cloud . . .	7·7	3·4	2·1	3·4	6·9	15·5	26·6	28·3	6·0	233

The table shows similar results to those already discussed for the balloon ascents. In the lower layers below 3500 ft. there are two principal directions of maximum wind frequency, one from the NW., the other from the S. Above this height the principal direction from the S. entirely disappears and the dominant direction becomes the W. to NW.

* G. C. Simpson, *British Antarctic Expedition, 1910–13*, p. 132.

4. DISTRIBUTION OF WIND AT DIFFERENT LEVELS IRRESPECTIVE OF DIRECTION; PILOT BALLOON ASCENTS

The results of the pilot balloon ascents have been analysed in order to determine the percentage frequency of winds within the velocity groups less than 2 m/s, 2 to 7 m/s, 8 to 14 m/s, 15 to 21 m/s, and greater than 21 m/s. The results for the seasons and year have already been given in a diagrammatic form for the various directions in fig. 23, but the results for the year, irrespective of direction, have been summarised in Table 58 below.

TABLE 58.—PERCENTAGE FREQUENCY OF WIND WITHIN STATED LIMITS OF VELOCITY AT DIFFERENT LEVELS IN THE UPPER ATMOSPHERE, 1932–33.

Height.	Velocity Limits in m/s.				
	< 2.	2–7.	8–14.	15–21.	⩾ 22.
feet.	%	%	%	%	%
Surface	18·6	63·3	18·0	0·3	
1,000	4·2	64·2	27·5	3·8	0·3
2,000	4·0	57·1	33·3	5·3	0·3
3,000	2·0	53·7	37·4	6·5	0·3
4,000	2·2	53·9	38·2	5·5	0·4
5,000	1·6	56·8	34·1	7·1	0·4
6,000	0·9	49·2	42·2	7·8	..
8,000	1·5	46·1	41·4	9·8	1·0
10,000	2·1	47·6	39·3	10·3	0·7
12,000	0·9	52·4	35·2	8·6	2·9
14,000	..	47·3	41·9	10·8	..
16,000	1·8	42·9	41·1	8·9	5·3
18,000	4·5	34·1	38·6	18·2	4·5
20,000	..	32·1	42·8	17·9	7·1

In the lower levels of the atmosphere and extending up to 16,000 ft. the most frequent wind velocity occurs in the limits 2 to 7 m/s; above 16,000 ft. and up to 20,000 ft. the most frequent wind velocity lies within the limits 8 to 14 m/s.

5. MEAN WIND VELOCITIES FROM DIFFERENT DIRECTIONS AT DIFFERENT LEVELS IN THE UPPER ATMOSPHERE, 1932–33

(a) *From pilot balloon ascents.*—The mean velocity of the wind from different directions has been determined from the observed values at all heights, and smoothed values have then been determined for each direction by forming means from three consecutive directions according to the formula $4\bar{b}=a+2b+c$. The smoothed values of the wind velocity have been entered in Table 59. The values in the brackets indicate that in one of the directions used to determine the smoothed value there were three or less observations.

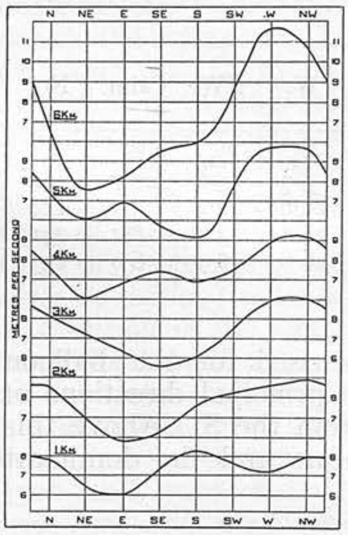


FIG. 25.—Mean wind velocity at different heights for different wind directions.

The values at the kilometre levels have been plotted against the direction in fig. 25, and the points have been joined by a smooth curve.

Up to the 1 km. level there are two principal directions of greatest mean velocity, one from the NW. and the other from the S. The directions of greatest mean velocity agree with the directions of maximum wind frequency up to this level.

Above the 1 km. level the maximum mean wind velocity is from the W. to NW., which also agrees with the direction of maximum wind frequency at these levels.

The secondary maximum of mean wind velocity from the S. entirely disappears at higher levels than 1 km.

At great altitudes the minimum velocity occurs from the NE. direction.

TABLE 59.—SMOOTHED VALUES OF THE MEAN WIND VELOCITY AT DIFFERENT HEIGHTS FOR DIFFERENT WIND DIRECTIONS (BALLOON ASCENTS), 1932–33.

Height.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Height.
feet.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	km.
1,000	6·04	4·81	5·64	6·99	6·44	5·34	5·87	6·85	
2,000	6·82	5·57	6·17	7·80	8·07	6·95	6·64	7·37	
3,000	7·83	6·39	5·98	7·31	8·25	7·61	7·23	7·97	1
4,000	8·16	6·71	6·00	7·01	7·74	7·26	7·32	8·24	
5,000	7·87	6·92	6·51	7·34	8·31	8·07	7·56	7·92	
6,000	8·39	6·91	5·75	6·25	7·57	8·23	8·55	8·89	2
8,000	8·43	6·55	5·58	6·13	7·24	8·38	9·45	9·62	
10,000	8·09	7·19	6·29	5·60	6·04	7·58	8·93	8·98	3
12,000	8·23	7·13	6·09	5·45	5·47	6·99	9·33	9·54	
14,000	7·65	6·02	(6·83)	(7·47)	(6·79)	(7·56)	8·94	9·15	4
16,000	7·24	(6·10)	(6·85)	(5·67)	(5·21)	(7·67)	9·71	9·60	5
18,000	(6·79)	(5·63)	(5·56)	(2·60)	(2·19)	(5·41)	9·48	9·74	
20,000	(6·34)	(3·50)	(4·25)	(5·50)	(5·92)	(8·70)	(11·73)	(10·55)	6

(b) *From nephoscope results.*—An analysis of the 663 nephoscope observations at the levels of cloud less than 3500 ft., 3500 to 7000 ft., medium cloud, and high cloud has been made to determine mean velocities from the different directions. The analysis leads to the following table:—

TABLE 60.—MEAN WIND VELOCITY AT DIFFERENT HEIGHTS FROM DIFFERENT DIRECTIONS (NEPHOSCOPE OBSERVATIONS), 1932–33.

Height.	N.	NE.	E.	SE.	S.	SW.	W.	NW.
	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.	m/s.
< 3500 ft. .	6·6	4·0	6·0	5·5	5·2	3·5	3·7	6·6
3500–7000 ft. .	8·7	9·3	12·0	7·4	7·8	5·7	6·3	8·2
Medium cloud .	19·2	16·4	10·3	19·5	10·2	12·7	12·6	15·7
High cloud . .	21·1	2·4	12·0	12·1	14·7	19·9	26·6	22·6

These values have also been represented in fig. 24, the values for the different directions being enclosed by an irregular octagon with dotted sides.

The results of the nephoscope observations do not show such close agreement with the results of the balloon ascents. In the layers below 3500 ft., the octagon of mean wind velocity is elongated in the NW. to SE. direction, which agrees with the results from the pilot balloon ascents.

In the interval 3500 to 7000 ft., the maximum mean wind velocity occurs from an E. direction; at the level of the medium cloud it occurs from the SE., although the mean velocity from the N. is nearly as large.

At the height of the high cloud, the maximum velocity again occurs from the W. to NW. with a minimum value from the NE. direction, confirming the results deduced from the balloon ascents for high altitudes of 20,000 ft.

6. RESULTANT WINDS IN THE UPPER ATMOSPHERE

The resultant winds during the seasons and the year have been calculated from the observations of balloon ascents, and the values have been entered in Table 61 below.

TABLE 61.—RESULTANT WINDS IN THE UPPER ATMOSPHERE, 1932–33.

Height.	Summer.		Equinox.		Winter.		Year.		Height.
feet.	m/s.	°	m/s.	°	m/s.	°	m/s.	°	km.
20,000	3·3	293	14·8	278	..	..	8·1	282	6
18,000	2·9	301	11·6	283	..	..	5·8	294	
16,000	3·3	290	8·0	292	..	..	4·9	291	5
14,000	3·5	288	6·3	297	..	..	4·5	293	4
12,000	2·8	292	6·6	294	10·5	300	4·4	294	
10,000	2·8	301	6·0	286	9·6	299	4·4	294	3
8,000	2·2	278	6·0	285	10·0	315	4·4	292	
6,000	2·1	272	5·0	292	7·8	310	4·0	293	2
5,000	1·5	247	3·6	281	5·7	316	2·6	286	
4,000	1·5	227	2·4	275	4·4	330	1·8	281	
3,000	1·1	204	1·7	269	3·4	323	1·2	272	1
2,000	1·2	173	0·9	214	3·1	316	0·7	230	
1,000	1·3	148	0·8	115	2·7	321	0·4	133	
Surface (P.B.)	0·6	111	0·6	62	1·6	335	0·5	81	Surface (P.B.)
Surface	0·47	77	0·86	11	1·94	328	0·88	351	Surface

The vector resultants for the kilometre levels have been represented in fig. 26.

In the table two surface values have been given, but the lower surface value corresponds to the resultant wind as determined from the hourly values of wind

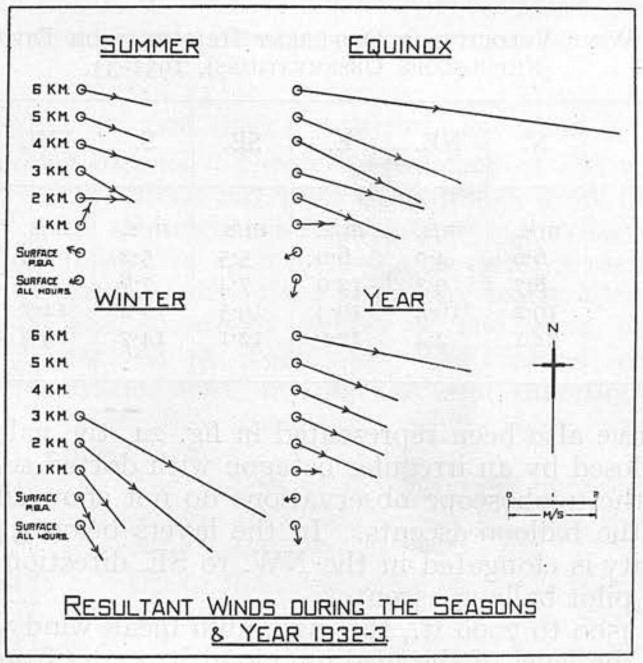


FIG. 26.

velocity, whereas the upper values correspond to the resultant wind as determined from the observations immediately before each ascent. The agreement in the magnitude of the resultant between the surface values is indeed quite satisfactory, though the agreement in direction is not quite as good.

Except for the winter season, the resultant wind veers steadily from its surface value to a NW. direction at about 6000 ft., remaining more or less NW. above this height up to 20,000 ft. During the winter the resultant from the surface up to 12,000 ft. remains from a NW. direction.

7. THE DIRECTION OF THE WIND IN THE UPPER ATMOSPHERE WHEN THE WIND AT THE SURFACE IS FROM STATED DIRECTIONS

Throughout the present discussion it has been repeatedly shown that the SE. and the NW. winds are the most important winds in the locality of Fort Rae. They are the most frequent wind directions at the surface, and they have the greatest mean velocities. It is now interesting to inquire whether, for example, a SE. wind at the surface remains a SE. wind at greater heights, or what percentage of the SE. winds remains SE. at greater heights. It has also been stated that from the results it appears that a SE. wind is usually a shallow wind, but that the NW. wind can remain NW. as a solid current extending at least up to 20,000 ft.

For the purpose of further inquiry, Table 62 has been prepared from the results of the pilot balloon ascents, each level being based solely on balloon ascents which have reached that level. Thus, if we consider the 3 km. level, the results show that of all the ascents which reached 3 km., 11% indicated surface winds from the N., 5% indicated surface winds from the NE., etc. Furthermore, of this 11% which indicated winds from the N. at surface level, at the 3 km. level only 25% remained N., 19% had become NE., 25% had become W., and 31% had become NW. With this understanding we can now consider the table.

TABLE 62.—DIRECTION OF THE WIND AT 1, 2, 3, 4, 5, AND 6 KILOMETRES IN THE UPPER ATMOSPHERE WHEN THE DIRECTION AT THE SURFACE IS N., NE., ETC., IN PERCENTAGE FREQUENCY, 1932–33.

Direction at Surface.	Percentage Frequency at Surface.	Percentage Frequency of Wind from									Direction at Surface.	Percentage Frequency at Surface.	Percentage Frequency of Wind from								
		N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.			N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.
		1 kilometre.											4 kilometres.								
N.	11	33	**36**	6	..	..	..	3	18	3	N.	8	**50**	..	..	..	..	..	17	33	..
NE.	4	9	**45**	..	9	18	9	..	9	..	NE.	4	33	**67**	..	..	..	..	..	..	..
E.	3	..	20	**40**	30	10	..	..	..	..	E.	3	..	..	**50**	..	..	**50**	..	..	..
SE.	**28**	..	1	2	21	**40**	27	6	1	1	SE.	**31**	..	4	4	4	4	29	**37**	17	..
S.	8	..	4	22	13	**26**	9	17	9	..	S.	15	17	8	17	..	8	17	**25**	8	..
SW.	2	..	..	..	..	17	**67**	..	17	..	SW.	1	..	..	..	..	..	..	..	..	..
W.	3	..	..	..	..	..	..	**55**	44	..	W.	3	..	..	..	..	..	**50**	**50**	..	..
NW.	**19**	33	2	5	2	4	2	5	**47**	..	NW.	**9**	..	14	..	..	14	14	**29**	**29**	..
Calm.	22	11	3	8	11	6	6	19	**32**	5	Calm.	27	14	5	5	..	5	5	19	**48**	..
		2 kilometres.											5 kilometres.								
N.	10	29	13	4	8	..	..	8	**37**	..	N.	3	**50**	..	..	..	..	..	..	**50**	..
NE.	4	**33**	**33**	..	..	..	22	11	..	..	NE.	5	33	**67**	..	..	..	..	..	..	..
E.	4	..	..	**44**	33	..	11	11	..	..	E.	3	..	..	**50**	..	..	**50**	..	..	..
SE.	**29**	3	1	1	13	9	**37**	25	10	..	SE.	**33**	..	5	5	5	10	10	**45**	20	..
S.	9	5	..	9	**29**	9	9	**29**	5	5	S.	13	**25**	13	13	13	..	..	**25**	13	..
SW.	2	..	..	..	..	..	**40**	**40**	20	..	SW.	2	..	..	..	..	..	..	**100**	..	..
W.	4	10	..	..	..	..	..	40	**50**	..	W.	2	..	..	..	..	..	..	**100**	..	..
NW.	**15**	15	..	3	..	3	..	18	**62**	..	NW.	**8**	..	20	..	..	..	20	**40**	20	..
Calm.	22	15	2	4	4	6	2	27	**40**	..	Calm.	30	11	6	..	..	..	11	28	**45**	..
		3 kilometres.											6 kilometres.								
N.	11	25	19	..	..	..	..	25	**31**	..	N.	0	..	..	..	..	..	..	..	..	..
NE.	5	**57**	14	..	..	..	14	..	14	..	NE.	4	..	..	**100**	..	..	..	..	..	..
E.	3	..	..	**40**	20	..	20	20	..	..	E.	4	..	..	..	..	..	..	**100**	..	..
SE.	**28**	2	..	5	14	12	24	**31**	9	..	SE.	18	..	..	..	..	..	**40**	20	**40**	..
S.	11	6	6	**19**	6	**19**	13	13	**19**	..	S.	18	..	..	20	20	..	..	**40**	20	..
SW.	2	..	..	..	..	..	**67**	33	..	..	SW.	4	..	..	..	..	..	..	**100**	..	..
W.	3	..	..	..	..	..	20	**60**	20	..	W.	4	..	..	..	..	..	**100**	..	..	..
NW.	**12**	17	..	..	6	11	6	28	**33**	..	NW.	18	20	..	..	..	..	**40**	20	20	..
Calm.	24	11	6	..	3	3	6	28	**45**	..	Calm.	**32**	..	..	..	..	..	..	44	**56**	..

A comparison of the percentage frequency at the surface corresponding to the different levels shows that for five of the levels, 1 km. to 5 km., the surface frequency shows very similar conditions. They all show that the greatest frequency occurs from the SE. at the surface, and there is a secondary maximum of frequency from the NW. The percentage of calms is also high in all. In fact, the percentages given for all directions of the surface wind agree exceedingly well for the five levels. It may therefore be said that ascents reaching the 5 km. level have been taken under similar conditions of the surface wind. It has also been previously stated that these surface conditions during pilot balloon ascents agree well with the surface conditions throughout the whole year, so that we may now say that all ascents which have reached the 5 km. level have been taken during surface conditions representative of the whole year. They have not been taken under specialised conditions at the surface.

An examination of the surface conditions during ascents up to the 6 km. level shows that, although there is some similarity in the surface frequency with those of the other groups, yet the similarity is not as good. The dominant frequency from the SE. has decreased, and the ascents have been made mainly during camls, so that these ascents have been made under slightly specialised surface conditions.

As the SE. and NW. winds, together with calms, are the most frequent at the surface, we shall only consider what happens to their direction with increasing altitude in the following discussion.

The SE. wind at the surface shows the greatest frequency from the S. at the 1 km. level, from the SW. at the 2 km. level, from the W. (with increasing frequency) at the 3 to 5 km. levels, and from the SW. and NW. at the 6 km. level. Thus, in general, a SE. wind veers with height from the surface up to the 3 km. level, beyond which it remains a solid current from the W. up to the 5 km. level at least.

The NW. surface wind shows the greatest frequency from the NW. at the 1 to 4 km. levels, from the W. at the 5 km. level, and from the SW. at the 6 km. level. It appears, therefore, that in general the NW. wind at the surface remains a NW. wind up to about 4 km., after which there is a steady backing with height to become W. to SW. at the 6 km. level.

Calms at the surface are associated in general with a NW. wind, extending up to the highest height attained of 6 km.

These statistical results obtained undoubtedly agree with the experience obtained during pilot balloon ascents, and it explains why it was practically impossible for us to arrange that a meteorograph balloon should fall into the territory NW. or N. of Rae, where, owing to the presence of Indian encampments, there was a greater opportunity of finding them. These meteorograph balloons, although released in a SE. wind, would invariably be lost in the distance either to the E. or SE. in country void of habitation. The two meteorographs that were ultimately found were discovered about 100 miles away: one to the SE., on the edge of the Slave Lake, and the other to the E., somewhere in the Barren Lands. Both were found by Indians when either hunting or visiting their trap lines.

These results are confirmed to a great extent by an examination of the nephoscope observations made upon medium and high cloud. The medium cloud would correspond to a height of from 3 to 4 km., whereas the high cloud will give results above the heights attained by the pilot balloons. A similar analysis was therefore carried out for the nephoscope observations, but here certain nephoscope observations which were excluded in § 3 (*b*) must now be included. It was there stated that whenever a sequence of nephoscope observations was recorded of the same direction during any one day, it was only entered once in the reduction of the data. But when one is, at the same time, considering two directions, the direction at the surface and the direction at the level of the medium or high cloud, a slightly different procedure has to be adopted. Whenever a sequence of the combination "nephoscope direction and surface wind direction" was obtained on any one day, it was only entered once in the reduction of the data. If, however, a sequence of nephoscope

TABLE 63.—THE DIRECTION OF WIND AT THE LEVEL OF THE MEDIUM AND HIGH CLOUD WHEN THE DIRECTION AT THE SURFACE IS N., NE., ETC. IN PERCENTAGE FREQUENCY, 1932–33.

Direction at Surface.	Percentage Frequency at Surface.	Percentage Frequency of Wind from								
		N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.
		Level of Medium Cloud.								
N.	**18·9**	4·6	6·9	4·6	1·5	2·3	16·2	26·2	**31·6**	6·2
NE.	5·4	..	**24·3**	2·7	16·2	5·4	18·9	**24·3**	8·1	..
E.	7·3	4·0	..	8·0	**22·0**	12·0	14·0	20·0	12·0	8·0
SE.	**29·5**	5·4	..	2·5	5·4	15·3	20·7	**24·6**	20·7	5·4
S.	8·4	8·6	..	6·9	6·9	17·3	13·8	19·0	**22·4**	5·2
SW.	4·9	..	11·8	5·9	..	8·8	20·6	5·9	**47·0**	..
W.	4·5	9·7	6·5	3·2	..	6·5	6·5	**35·4**	32·2	..
NW.	15·2	12·3	7·6	1·0	..	1·0	17·1	**32·4**	26·7	1·9
Calm.	5·8	..	10·0	..	..	15·0	20·0	20·0	**25·0**	10·0

Direction at Surface.	Percentage Frequency at Surface.	Percentage Frequency of Wind from									Percentage Frequency at Surface.
		N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.	
		Level of High Cloud.									Hourly Values.
N.	13·5	10·0	2·0	2·0	5·0	9·0	**24·0**	23·0	21·0	4·0	12·9
NE.	3·1	4·3	..	..	8·7	8·7	**43·5**	26·1	8·7	..	4·8
E.	5·1	..	7·9	5·3	..	18·4	23·7	**36·8**	7·9	..	4·2
SE.	**37·7**	7·1	3·6	0·3	4·6	8·9	21·4	24·4	**28·3**	1·4	**28·5**
S.	9·9	5·5	4·1	1·4	6·8	5·5	26·0	**27·4**	23·3	..	6·6
SW.	3·1	4·3	..	..	8·7	..	26·1	21·7	**34·8**	4·3	2·1
W.	4·5	9·1	..	3·0	..	..	9·1	30·3	**39·4**	9·1	4·8
NW.	**13·8**	12·6	..	1·0	4·9	4·9	10·7	**36·8**	29·1	..	**17·7**
Calm.	9·3	8·7	2·9	8·7	2·9	5·8	..	20·3	**47·8**	2·9	18·6

directions remained the same throughout the day, but at each such observation the surface wind direction changed, then all such observations would be entered in the reduction of the data. With this procedure many of the nephoscope results which were before excluded are now included, and the observations of the medium cloud are increased from 231 to 344 and the high cloud from 233 to 371.

The results have been entered in Table 63, where in the last column, for the purpose of comparison, the percentage frequency at the surface for the year 1932–33, as obtained from hourly values, has been entered.

An examination of the frequency at the surface from hourly values, and those at the surface corresponding to the observations of medium and high cloud, shows again great similarity. The three surface frequencies show the principal maximum from the SE. and the secondary maximum from the NW. or N. Even the individual values do not differ by very large amounts, the greatest difference being for the observations of high cloud during SE. surface winds. Consequently, it may again be stated that the surface winds during the observations of medium and high cloud agree very closely with the surface winds of the year as a whole, and have not been taken under a particular set of surface wind conditions.

The SE. surface wind shows the greatest frequency from the W. at the level of the medium cloud and from the NW. at the level of the high cloud. In fact, during the period of SE. wind at the surface, 66% of the observations show a wind from the SW. to NW. at the level of the medium cloud, and 74% of the observations show a wind from the SW. to NW. at the level of the high cloud. These statements are in agreement with the results of the pilot balloon ascents.

The NW. surface wind shows the greatest frequency from the W. at the level of the medium and high cloud. During the period of NW. winds at the surface, 76% of the observations at the level of the medium cloud and 77% at the level of the high cloud show a wind from the SW. to NW.

Calms at the surface are also mainly associated with NW. winds at the level of the middle and high clouds.

All the foregoing results from the nephoscope observations agree with the conclusions of the pilot balloon ascents.

It is of interest, further, to determine the average annual veer or backing of the upper winds from its surface direction. For this purpose all the balloon ascents have been analysed at the km. levels, a veer being counted as positive and a backing wind with height as negative. In some cases, however, calms have been observed at a particular level, and in these cases the backing or veering from the lower level to the upper level above the region of calm has been divided between the two intervals. The direct mean values have been entered in Table 64 and are represented in fig. 27,

TABLE 64.—AVERAGE ANNUAL TURNING OF THE WIND FROM THE GROUND UP TO GIVEN LEVELS RECKONED IN DEGREES, POSITIVE FOR A VEER, NEGATIVE FOR A BACKING.

Interval of Height.	Direction at the Surface from							
	N.	NE.	E.	SE.	S.	SW.	W.	NW.
km.	°	°	°	°	°	°	°	°
0–6	..	..	..	+71	+25	+50	−55	−18
0–5	−30	−36	+72 *	+62	+17	+50	−25	−18
0–4	−20	−34	+60 *	+62	− 2	+45	−23	−17
0–3	− 6	− 7	+ 6	+62	+31	+37	+14	+ 4
0–2	+11	+15	+ 6	+65	+29	+30	+21	+ 3
0–1	+17	+31	+20	+41	+21	+11	+15	+14
0–$\frac{2}{3}$	+14	+21	+20	+32	0	+ 7	+15	+10
0–$\frac{1}{3}$	+ 9	+ 8	+10	+11	+ 3	0	+13	+10

* 2 observations.

from which the direction at any height corresponding to any given direction at the ground can be read.

It is seen that if the direction at the surface is W., NW., N., or NE., the wind veers with height up to the 3 km. level, beyond which there is a general backing up to 5 km. and probably 6 km. If, however, the wind at the surface is E., SE., S.,

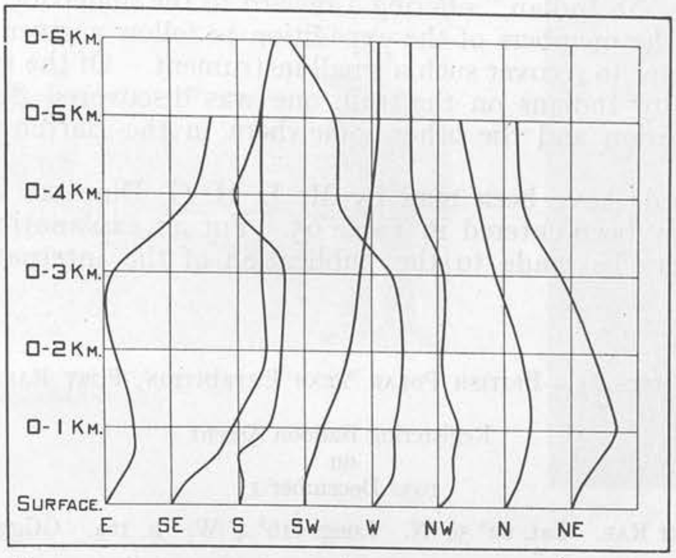


FIG. 27.—Average annual turn of the wind from the ground up to given levels.

or SW., the wind veers with height up to the 6 km. level. It appears from the figure that there is a general tendency for the lines to converge at the 6 km. level to within the SSW. and the WNW. directions.

PART V.—UPPER AIR TEMPERATURE AND PRESSURE

An attempt was made during the period of the expedition at Fort Rae to obtain soundings of the upper atmosphere into the levels of the stratosphere. For this purpose 48 Dines meteorographs * were taken with the expedition, each instrument having been originally calibrated at Kew Observatory before departure. The meteorographs were very carefully packed before being shipped to Fort Rae, but as there was still some risk of a zero change or slight damage to the aneroid occurring during transit, each instrument was again calibrated before ascent by small reductions of pressure in a chamber specially prepared by Mr L. H. G. Dines, at Kew Observatory, for this purpose. An examination of the trace of the scriber on the plate during this minor calibration would reveal whether the meteorograph had been damaged in transit. In the event also of a small zero change, the new trace would give the magnitude of the change. Of the 30 instruments tested at Fort Rae, not one had to be discarded through any change occurring after the calibration at Kew Observatory. The expedition had no facilities for detecting the small zero change, and if any occurred it could be taken into account when finally reading the record under a microscope.

There were numerous difficulties associated with the meteorograph ascents. It was found easier to release balloons with their attached instruments during the winter than during the summer months. Altogether 27 meteorographs were released during the year, and of these 20 were released in the winter months from December to

* A full description of the instrument can be found in a monograph entitled, *The Dines Balloon Meteorograph and the Method of using it*, by L. H. G. Dines, M.A., published by the Meteorological Office.

April. The main difficulty, however, connected with the meteorographs lay in retrieving them after their descent. To facilitate recovery, the spider supporting the instrument had trailing behind it 300 to 400 yards of red tape, together with red silk flags attached to each corner. It was hoped that the red silk and tape would show up boldly against the snow. Also attached to the spider was an inscription written in English and "Dog Rib Indian," offering a reward to the finder for recovery. It was impracticable for the members of the expedition to follow a given bearing from the station in an attempt to recover such a small instrument. Of the two meteorographs ultimately found by Indians on the trail, one was discovered 80 to 100 miles to the SE. of the station and the other somewhere in the Barren Lands E. of the station.

The two records have been read by Mr L. H. G. Dines at Kew Observatory, and the results have been entered in Table 65. For an explanation of the symbols used, reference may be made to the publication of the International Aerological Commission.

TABLE 65.—BRITISH POLAR YEAR EXPEDITION, FORT RAE.

Registering Balloon Ascent
on
1932 December 1

at FORT RAE. Lat. 62° 50′ N. Long. 116° 4′ W. h. 164. GGgg 2104.

B. I.

PS.	TS.	FS.	WS.	VS.	N.	B.
993	41	75	337	4	0	Pirelli.

FB.	Fa.	J.	FJ.	AB.	AW.	LM.	PM.	TM.
·75	·65	Dines	·13	150	131	17,225	72	18

$\underbrace{\text{AB. AW.}}_{\text{approx.}}$

B. II. LTF/P.

P.	L.	T.	F.
1000	..	..	..
900	850	48	..
800	1,685	47	..
700	2,625	45	..
600	3,705	42	..
500	4,950	34	..
400	6,410	24	..
300	8,225	16	..
200	10,770	21	..
100	15,165	20	..

B. III. PTF/L.

L.	P.	T.	F.
500	947	45	..
1,000	882	48	..
2,000	765	47	..
3,000	664	44	..
4,000	575	40	..
5,000	496	34	..
6,000	426	26	..
7,000	364	22	..
8,000	311	17	..
9,000	265	18	..
10,000	226	20	..
11,000	193	21	..
12,000	165	21	..
13,000	141	21	..
14,000	120	20	..
15,000	102	20	..
16,000	87	18	..
17,000	75	18	..
18,000	..	..	..
19,000	..	..	..

B. IV. LPTF.

L.	P.	T.	F.
Changes of lapse rate at:			
1070	873	48	..
3250	640	43	..
7760	323	17	..
8390	292	16	

(*a*) Launch of meteorograph. The figures from left are Morgans, Stephenson, and Grinsted.

(*b*) Morgans controlling action of hydrogen generator in summer.

(*c*) Comprehensive view of meteorological hut, anemometer, Stevenson screen, auroral shelter, and pilot balloon theodolite from NW. of the island.

(*d*) View looking NW. from roof of meteorological hut, showing main outdoor meteorological equipment and table for air-earth current observations.

(*e*) The broken and archipelagoed shore-line of the lake between the main station and Old Fort Rae.

(*f*) Old Fort Rae with the auroral camera enclosure.

TABLE 65 (*continued*).—BRITISH POLAR YEAR EXPEDITION, FORT RAE.

Registering Balloon Ascent
on
1933 January 26

at FORT RAE. Lat. 62° 50′ N. Long. 116° 4′ W. h. 164. GGgg 2120.

B. I.	PS.	TS.	FS.	WS.	VS.	N.	B.	
	985	43	75	350	2	3	Pirelli.	
	FB.	Fa.	J.	FJ.	AB.	AW.	LM.	PM.	TM.
	·73	·59	Dines	·13	?	?	16,680	83	35

B. II. LTF/P.

P.	L.	T.	F.
1000	..	..	..
900	800	52	..
800	1,665	56	..
700	2,640	52	..
600	3,740	46	..
500	5,015	39	..
400	6,515	28	..
300	8,330	14	..
200	10,865	22	..
100	15,415	34	..

B. III. PTF/L.

L.	P.	T.	F.
500	938	49	..
1,000	876	56	..
2,000	764	55	..
3,000	666	49	..
4,000	578	45	..
5,000	501	39	..
6,000	432	32	..
7,000	371	24	..
8,000	316	15	..
9,000	269	16	..
10,000	230	21	..
11,000	196	23	..
12,000	168	27	..
13,000	144	29	..
14,000	124	31	..
15,000	107	33	..
16,000	92	34	..
17,000	..	..	..
18,000	..	..	..
19,000	..	..	..
20,000	..	..	..
21,000	..	..	..

B. IV. LPTF.

L.	P.	T.	F.
Top of Inversion			
1310	840	57	..
Stratosphere			
8530	290	13	..

PART VI. CLOUD

1. GENERAL

There is no doubt that, under arctic conditions, cloud is one of the most difficult meteorological elements to discuss in a satisfactory manner. All the observations of cloud, both as regards form and amount, are eye observations, and such estimates depend too much on personal factors. Observers will differ as to the form and the amount of cloud. But the difficulties under arctic conditions are much more subtle, even for experienced observers.

It frequently happens that the sky is covered by a very thin haze, which is often so thin as hardly to be noticeable. The difficulty under such conditions is to determine whether the cloud amount should be represented by 0 or 10. There were frequent cases of such difficulty at Rae, the most interesting one undoubtedly occurring on 1933 April 7. The colour of the sky was mainly blue with a very faint tint of white, but it was only after the fall of a shower of exceedingly fine ice crystals and after the sky had been examined very carefully that a faint tint of white was noticed. Some of the observers still do not agree that there was a tint of white in the colouring of the sky. The examination of the sky was made more difficult by the fall of ice crystals themselves. It is interesting to note the entry in the register as Cist 10/10, very thin, but the Beaufort letters were given as bz_0, the slight haze being produced by the falling ice crystals. After the cessation of the ice crystals, it is true that the sky was covered with Ci, Cist, but this gives no evidence as to the sky-covering during the preceding observation. It is definitely unsatisfactory when such a sky has to be given the same weight as a completely overcast sky of thick Nbst.

Again, during the winter months some days are exceedingly dull, and it is only with great difficulty Ast can be differentiated from St or Nbst. At night the difficulty is much worse. It is extremely difficult to differentiate between Cist, Ast, St, and Nbst during a moonless night. It is true that there are certain aids such as precipitation, but this in itself is entirely unsatisfactory. Even when there is a moon enabling the observer to see coronæ or halos, the difficulties are not thereby decreased. Frequently the cloud-sheet at night did not appear to change its form, but in spite of this it was common to see at one period a lunar corona, at another a lunar halo reverting at a later stage to a corona, and at others a corona and a halo together. It is known that even low clouds are frequently formed of ice crystals and are therefore in the nature of Ci clouds, so that an experienced observer often finds difficulty in deciding whether the cloud form should be described as St, Ast, or Cist. The presence of coronæ or halos do give a criterion as to whether the cloud is composed of ice crystals or water droplets, but it gives no criterion as to whether the cloud is low or high. When a lunar corona and halo coexist there is another difficulty. On these occasions it generally appeared as if the sky was covered by a very thin St or Ast sheet which gave the corona, but the cloud was so thin as to allow the halo, formed probably by a higher layer of Cist, to be seen through it. The observer is then faced with the difficulty of deciding what clouds and what amounts are to be entered in the register. There was no evidence to indicate two cloud-sheets, or even two separate forms of cloud apart from the coexistence of the two optical phenomena.

From personal experience, however, the greatest asset in determining the cloud forms was the presence of bright aurora, especially during nights of broken cloud. During nights of overcast sky, the cloud would be thick before bright aurora became obscured, and on these nights the same difficulties arose of determining whether the cloud was thick Ast, St, or Nbst.

The cloud at night was of great interest, and it will be discussed at length later, but it will suffice to say at present that particular care was taken to try to determine not only the cloud form but the cloud amount. All the observations, however, are subject to the inherent difficulties mentioned above, both as regards form and amount.

During the Second Polar Year Expedition to Fort Rae eight standard observations of cloud were made daily from August 1 to October 6, 1932, but on the latter day it was decided to carry out hourly observations, as far as possible, throughout the year. By reference to the data such as the auroral log, the Beaufort letters in the pocket register, the sunshine records, and by memory of actual circumstances, the hourly values of cloud were interpolated for the preceding six days of October, in order that the hourly values of cloud for that month should be complete. Thereafter, hourly values of cloud were made throughout the year except on occasions at 3h and 4h. After 2h there was normally a change of observer to continue the auroral watch; but if the sky was overcast and there seemed no prospect of the cloud-sheet breaking, or if there was an absence of aurora, then the observer would remain undisturbed until the 5h observation. Frequently the sky was overcast at the 2h and 5h observation, so that on these occasions interpolated values of cloud have been entered, usually of amount 10, of the form under consideration. During the summer, with the absence of aurora, the same procedure continued. On occasions the observations at 2h and 5h differed both in form and amount from one another, so that it became difficult to interpolate for the 3h and 4h. Such cases have been treated on their merits, and when it was thought inadvisable to interpolate, the whole day has been discarded in the formation of diurnal inequalities and means, etc.

The data for the year 1882–83 are based upon hourly observations of cloud from September 1882 to August 1883 inclusive, but in that year only a few cloud forms, namely St, Nb, Stcu, Cu, Cicu, Cist, and Ci, were recorded.

During 1932–33, however, the cloud forms recorded were based upon the full range of clouds in the International Cloud Atlas, and this fact has to be taken into consideration in the comparison of the two years.

2. PERCENTAGE FREQUENCY OF DIFFERENT CLOUD FORMS

The observations for the two years have been examined, and all the cloud forms have been counted and classified under twelve classes for the year 1932–33 and under seven classes for the year 1882–83. During 1932–33 no attempt has been made to differentiate between the cloud forms entering each class for the purpose of Table 66. Thus, observed Acu lenticular and Acu castellatus have been entered for the purposes of the table under Acu; delicate Ci and dense Ci, etc. have been entered under Ci. But as Stcu was a very frequent cloud at Rae, and as there was associated with the Stcu such cloud forms as St, Frst, Nbst, Cu, and Frcu, it was decided to separate these cloud forms from the pure St, Frst, etc. These observations, however, have still been entered under the appropriate cloud form, but they have been given a separate column such as St associated with Stcu. Another common entry was the combination Acu-Ast, or Ci-Cist, no amounts being given for each form, owing to the impossibility of doing so. These associated forms occur very frequently throughout the year and especially during the winter months. They have been separated from the entries Acu or Ast which occurred alone, or from Ci or Cist which occurred alone; and in Table 66, which gives the percentage frequency of cloud forms, it is to be noted that an entry such as Acu, Ast together has been given one count and not two corresponding to the two forms Acu and Ast. The same applies for an entry Ci, Cist occurring together.

Table 66, therefore, gives the percentage frequency of the different cloud forms which occurred during the two Polar Years, together with the total number of cloud forms noted.

An examination of the table shows that for 1932–33 the annual variation of the frequency of Stcu shows a particularly well-marked maximum in the month of October and a secondary maximum in the month of June. The annual variation of the frequency of St cloud also shows a particularly well-marked maximum in the month of October, the three months October, November, and December showing a much larger frequency than any of the other months. Owing to these types of annual variations, the annual variation of the St, Stcu clouds together shows a marked maximum in the month of October and a secondary maximum in the month of June. The annual variation of the frequency of Nbst shows a maximum in the month of November and a minimum in June. These three cloud forms are the most important of the lower cloud forms observed, and as they generally covered the whole sky it will not be surprising to see at a later stage, when considering the cloud amount, that the annual variation of cloud amount is governed to a large extent by the annual variation of the low cloud, and follows in its general character the annual variation of the frequency of the St and Stcu clouds.

The table again shows that, for 1932–33, the convection clouds Cunb and Cu are more frequent during the summer months, although Cicu occurred throughout the year. Acu was frequent in all months of the year, the maximum occurring in the winter month of January. The frequency of Acu is, however, misleading as to the manner in which Acu appears throughout the year. The entries indicate that Acu during the winter only appeared in small amounts, the entry "Acu, trace," being a very common entry.

The percentage frequency of cloud forms during 1882–83 shows a marked disagreement with the results of 1932–33, which is not surprising when it is considered that throughout the whole year only seven forms of cloud have been entered. There are no cloud forms corresponding to Acu, Ast, or Cunb, etc. Even when the cloud forms St, Nb, Stcu, and Cu are considered as low clouds, and the cloud forms Cicu, Cist, and Ci are considered as high clouds, there is still striking disagreement between the results of the two years.

TABLE 66.—PERCENTAGE FREQUENCY OF CLOUD FORMS, 1932–33.

Month.	St, Frst.		Nbst.		Stcu.	Cu, Frcu.		Cunb.	Ast.	Acu.	Acu, Ast.	Cicu.	Cist.	Ci.	Ci, Cist.	No. of Cloud Forms.
	Pure.	With Stcu.	Pure.	With Stcu.	Pure.	Pure.	With Stcu.	Pure.	Pure.	Pure.	To-gether.	Pure.	Pure.	Pure.	To-gether.	
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
1932 Aug.	3·5	1·2	3·3	0·2	10·4	**12·9**	2·3	4·8	2·9	21·6	4·8	**4·4**	3·3	**18·5**	6·0	482
Sept.	3·3	1·2	3·5	0·7	24·1	8·7	5·4	1·6	7·3	15·5	5·6	2·8	4·4	11·9	4·0	427
Oct.	16·4	**8·3**	9·6	**2·4**	**29·7**	2·7	3·8	1·2	5·9	8·8	2·3	1·1	2·8	3·1	1·8	1074
Nov.	17·7	2·3	**19·9**	1·6	8·1	0·0	0·2	0·0	3·7	13·1	3·5	2·2	14·0	5·7	8·0	827
Dec.	**17·9**	4·6	6·1	0·2	14·4	0·0	0·0	0·0	6·3	19·4	4·9	0·5	12·7	4·1	8·9	958
1933 Jan.	10·4	3·1	15·0	0·5	8·7	0·1	0·0	0·0	6·3	**26·0**	5·7	0·9	9·0	4·7	9·5	807
Feb.	6·4	0·9	9·2	0·5	4·7	0·0	0·0	0·0	**16·7**	13·5	7·4	0·9	**18·1**	4·1	17·6	780
Mar.	6·8	1·9	9·7	0·2	10·6	0·4	0·3	0·5	12·1	16·8	7·2	1·9	13·3	5·2	13·0	974
Apr.	2·6	4·5	6·5	1·7	18·2	0·6	0·8	0·0	6·7	15·9	**8·1**	1·1	12·8	2·0	**18·5**	961
May	2·4	3·8	8·7	0·8	15·4	9·7	1·6	4·2	4·8	14·6	4·7	0·2	9·5	5·7	13·8	1276
June	1·5	5·1	1·6	1·0	**22·5**	10·6	**7·7**	5·4	3·1	15·4	3·1	2·7	4·3	7·5	8·5	1622
July	1·0	2·5	2·3	1·0	19·5	11·0	7·5	**8·0**	1·8	16·8	2·5	3·3	3·1	4·2	15·5	1875
Aug.	0·5	2·5	1·8	1·3	15·7	12·2	6·3	6·5	1·8	21·0	3·4	2·0	3·1	8·3	13·6	1751

TABLE 66 (*continued*).—PERCENTAGE FREQUENCY OF CLOUD FORMS, 1882–83.

Month.	St.	Nb.	Stcu.	Cu.	Cicu.	Cist.	Ci.	Total Number of Cloud Forms.
	%	%	%	%	%	%	%	
1882 Sept. .	26·3	6·5	27·4	13·8	9·9	14·1	2·6	886
Oct. .	58·6	21·2	8·3	1·0	4·7	4·0	2·2	793
Nov. .	67·7	14·8	0·3	0·3	4·4	11·1	1·4	730
Dec. .	62·5	13·3	4·4	0·7	4·0	11·5	3·6	702
1883 Jan. .	66·2	7·8	5·8	0·4	0·7	16·4	2·7	550
Feb. .	55·1	18·9	10·6	0·2	1·1	13·8	0·3	615
Mar. .	56·4	1·8	11·7	1·8	0·7	24·3	3·3	545
Apr. .	41·3	3·5	31·1	1·5	3·6	15·5	3·5	803
May .	26·9	3·8	35·7	9·3	4·5	16·3	3·5	990
June .	18·9	5·6	44·4	10·2	3·3	15·3	2·3	1173
July .	21·9	3·9	31·3	18·7	6·3	13·4	4·5	1265
Aug. .	26·9	4·5	22·0	15·9	7·2	18·3	5·2	1299

In order to bring out the character of the sky during the year 1932–33, the percentage frequency for the stratified forms (St, Frst, Nbst, Ast, Cist, Ast associated with Acu, and Cist associated with Ci) have been combined together for all the months of the year, and have been entered in Table 67. Likewise the percentage frequency of the cumuli forms of cloud (Stcu, Cu, Frcu, Cunb, Acu, Cicu, and Acu associated with Ast) have been combined and entered in the same table. In this table it is to be noticed that the Ci form has been omitted, and further, that the percentage frequency corresponding to the form Acu and Ast together has been incorporated, both in the stratified forms and the cumuli forms.

It will therefore be seen that the sum of the percentages, stratified form and cumuli form, for any month will not make 100%.

The table also includes for the same year the percentage frequency of low cloud and high cloud forms.

The table shows that the stratified forms of cloud reach their maximum frequency during the winter months November to February, whereas the cumuli forms have their maximum frequency during the summer months May to August. Owing to this, the sky in the winter has a dull and monotonous appearance, whereas in the summer and spring the sky is much more varied.

The annual variation of the percentage frequency of low cloud forms shows a well-marked maximum in the month of October, a minimum in February, and a secondary maximum in June. This type of annual variation has also been shown to be characteristic of the St, Stcu cloud forms, the most frequent of low cloud forms.

TABLE 67.—PERCENTAGE FREQUENCY OF CLOUD FORMS, 1932–33.

Year.	Forms.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
		%	%	%	%	%	%	%	%	%	%	%	%
1932	Stratified forms, including St, Frst, Nbst, Ast, Cist;	..	..	..	..	..	..	..	**25·2**	30·0	49·5	70·7	61·6
1933	Ast and Cist associated with Acu and Ast respectively.	59·5	**76·8**	64·2	61·4	48·5	28·2	29·7	28·0	..	..	..	..
1932	Cumuli forms, including Stcu, Cu, Frcu, Cunb,	..	..	..	..	..	..	..	61·2	63·7	49·6	27·1	39·2
1933	Acu, Cicu, and Acu associated with Ast.	41·4	**26·5**	37·7	44·7	50·4	67·4	**68·6**	67·1	..	..	..	..
1932	Low cloud, including St, Frst, Nbst, Stcu, Cu,	..	..	..	..	..	..	..	38·6	48·5	**74·1**	49·8	43·2
1933	Frcu, Cunb.	37·8	**21·7**	30·4	34·9	46·6	**55·4**	52·8	46·8	..	..	..	..
1932	High cloud, including the	..	..	..	..	..	..	..	61·4	51·5	**25·9**	50·2	56·8
1933	the rest of cloud forms.	62·2	**78·3**	69·6	65·1	53·4	44·6	47·2	53·2	..	..	..	..

3. CLOUD AMOUNT: PERCENTAGE FREQUENCY OF EACH CLOUD AMOUNT

The mean cloud amount for the two years 1882–83 and 1932–33 was 5·5 and 6·1 respectively, giving a mean of 5·8. The mean amount of low cloud during eleven months of the year 1932–33 was 3·5. The mean amount of cloud, however, does not give a satisfactory indication of the cloud conditions during the year, and for this purpose the number of occasions of each cloud amount has been obtained for the two years. A cloud amount given as trace during 1932–33 has for statistical purposes been given a value of $\frac{1}{2}$, and the number of cases with cloud amount $\frac{1}{2}$ has been equally distributed between amounts 0 and 1. Likewise, a cloud amount 9+ has for statistical purposes been given a value $9\frac{1}{2}$, and the number of cases with cloud amount $9\frac{1}{2}$ has been equally distributed between amounts 9 and 10.

The results for the two years are given in Table 68, from which it is seen that, in general, days of clear sky or overcast sky are more frequent than any other type of day. The frequency decreases from the maxima at cloud amounts 0 or 10 towards the centre of the scale, showing a marked tendency for the sky to be either clear or overcast. In many of the seasons, however, cloud amount 1 is greater than cloud amount 0; likewise, amount 9 is greater than amount 10. There appears to be no evidence why this should be the case, as there was no geographical feature at Rae around which one could always expect cloud. Such increased frequencies at amounts 1 and 9 are probably purely accidental, and in order to eliminate such

TABLE 68.—PERCENTAGE FREQUENCY OF EACH CLOUD AMOUNT.

Season.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
	%	%	%	%	%	%	%	%	%	%	%
	1882–83.										
Spring . .	21·3	16·4	7·7	5·7	6·5	3·9	4·4	4·3	5·7	9·5	14·7
Summer . .	2·9	10·5	7·9	7·9	7·3	5·6	6·9	8·6	11·5	16·7	14·3
Autumn . .	6·3	10·8	5·9	3·7	3·3	3·3	4·7	4·5	7·2	17·5	32·7
Winter . .	19·9	10·7	8·1	6·5	5·0	3·9	3·7	4·7	3·6	6·1	27·8
Equinox . .	13·8	13·6	6·8	4·7	4·9	3·6	4·5	4·4	6·5	13·5	23·7
Year . . .	12·2	11·6	7·6	6·4	5·7	4·4	5·0	5·9	7·2	12·1	21·9
	1932–33 (13 months).										
Spring . .	14·9	13·3	3·5	3·4	3·9	2·2	2·3	2·7	5·1	17·7	30·9
Summer * . .	6·5	15·3	7·2	5·5	4·1	3·0	4·0	4·8	8·7	16·7	24·3
Autumn * . .	8·4	11·0	3·1	3·1	3·5	2·5	2·3	2·1	4·0	17·9	42·1
Winter . .	20·4	12·3	4·6	2·6	2·6	2·9	2·1	2·5	3·8	10·1	36·1
Equinox . .	10·7	14·3	5·3	4·5	4·0	2·6	3·1	3·7	6·9	17·2	27·6
Year . . .	12·8	13·3	5·0	3·8	3·5	2·8	2·8	3·2	5·7	14·8	32·3
	Combined Years (25 months).										
Spring . .	18·1	14·9	5·6	4·5	5·2	3·1	3·3	3·5	5·4	13·6	22·8
Summer . .	4·7	12·9	7·5	6·7	5·7	4·3	5·5	6·7	10·1	16·7	19·3
Autumn . .	7·3	10·9	4·5	3·4	3·4	2·9	3·5	3·3	5·6	17·7	37·4
Winter . .	20·2	11·5	6·3	4·6	3·8	3·4	2·9	3·6	3·7	8·1	31·9
Equinox . .	12·3	13·8	6·1	4·6	4·4	3·4	3·8	4·1	6·7	15·3	25·6
Year . . .	12·5	12·5	6·3	5·2	4·6	3·6	3·9	4·5	6·4	13·4	27·1

TABLE 69.—PERCENTAGE FREQUENCY OF THREE GROUPS OF CLOUD AMOUNT.

Season	1882–83.				1932–33.				Combined Years.			
	0–1.	2–8.	9–10.	Mean Cloud Amount.	0–1.	2–8.	9–10.	Mean Cloud Amount.	0–1.	2–8.	9–10.	Mean Cloud Amount.
	%	%	%	%	%	%	%	%	%	%	%	%
Spring .	37·7	38·1	24·2	4·3	28·2	23·2	48·6	6·0	33·0	30·6	36·4	5·1
Summer *	13·4	55·6	31·0	5·9	21·8	37·2	41·0	6·0	17·6	46·4	36·0	5·9
Autumn *	17·1	32·7	50·2	6·7	19·4	20·6	60·0	7·0	18·2	26·7	55·1	6·9
Winter .	30·6	35·5	33·9	5·0	32·7	21·1	46·2	5·7	31·7	28·3	40·0	5·3
Equinox *	27·4	35·4	37·2	5·5	25·0	30·2	44·8	6·5	26·1	33·0	40·9	6·0
Year * .	23·8	42·2	34·0	5·5	26·1	26·8	47·1	6·1	25·0	34·5	40·5	5·8

* The August value used is the mean of August 1932 and 1933. August and September 1932 are based on eight daily observations. The year is based on thirteen months for 1932–33.

irregularities the frequencies have been grouped around the amounts 0–1 as clear days, 9–10 as overcast days, and 2–8 as cloudy days. These values have been entered in Table 69.

The results of the combined years indicate that for all seasons overcast days are more frequent than clear days, and this is most marked in the autumn, not only for the combined years, but also for the individual years.

4. ANNUAL VARIATION OF CLOUD

Table 70 gives the monthly variation of the total cloud amount for the two years as departures from the mean of the year. The direct mean of the two years has been smoothed by the formula $4\bar{b}=a+2b+c$, and the values have been plotted in fig. 28, marked total cloud.

Table 71 gives also the monthly variation of the amount of low cloud for eleven months of the year 1932–33. These values have also been plotted in fig. 28, and the values have been joined by straight lines. The September value is not available.

Table 72 gives the monthly variation of percentage frequency of clear skies (0–1) for the two years as departures from the mean of the year. The direct mean has also been smoothed by the preceding formula, and plotted in fig. 28, but the values have all been inverted.

Table 73 gives the monthly variation of percentage frequency of overcast sky (9–10) for the two years, and the smoothed values have been plotted in fig. 28.

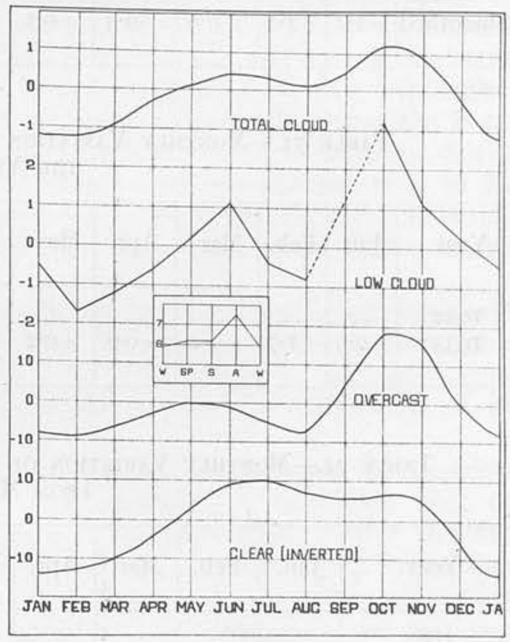


FIG. 28.—Annual variation of total and low cloud amounts, overcast and clear sky.

An examination of the figure shows that the annual variation of the cloud is well marked, while its variations are followed very closely by the variation of low cloud and the frequencies of clear and overcast sky. In fact, judging from one year's results, the annual variation of the total cloud is mainly governed by the annual variation of the low cloud.

The variation of the total cloud shows a principal maximum in October, a minimum in January and February, and a secondary maximum in June. The variation of low cloud amount shows a similar variation. In fact, another curve could equally well be drawn in fig. 28 which would show the same type of annual variation. This curve would be the percentage frequency of the St and Stcu cloud forms previously mentioned.

The secondary maximum during the summer is probably explained by the increase in the frequency of convection clouds, which during the long days of incoming radiation remain in the sky for considerable periods. It has already been seen that the percentage frequency of Cu, Cunb, and even Stcu forms shows a marked increase during the summer months. Probably associated with this secondary maximum in the summer is also the minimum during the winter months January and February. Shaw has shown that when thin clouds lose their heat by radiation, evaporation takes place, so that the more rapid the radiation the more rapidly do the clouds disperse. At Rae during the winter months the conditions are quite suitable for large and rapid radiation from the clouds. Speaking generally, the clouds are, on the whole, thin during the winter months, though no detailed evidence is to hand on this point, as the density of the cloud-sheets was not always entered in the register. The cloud-sheets, on the whole, being thin are able to

TABLE 70.—MONTHLY VARIATION OF TOTAL CLOUD AMOUNT (0–10) FROM MEAN OF THE YEAR.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
1882	..	..	..	..	..	..	..	..	+0·3	+2·1	+1·4	−0·6	
1883	−2·2	−0·5	−2·5	+0·2	−0·5	+0·9	+0·6	+0·8	..	..	..	..	5·5
1932	..	..	..	..	..	..	..	−1·4*	0·0*	+1·8	+0·6	+0·2	
1933	−1·6	−0·9	−0·4	+0·2	−0·1	+0·8	−0·4	−0·2	..	..	..	..	6·1
Mean	−1·9	−0·7	−1·5	+0·2	−0·3	+0·9	+0·1	0·0*	+0·1	+1·9	+1·0	−0·2	5·8
Smoothed	−1·2	−1·2	−0·9	−0·3	+0·1	+0·4	+0·3	+0·1	+0·5	+1·2	+0·9	−0·3	

TABLE 71.—MONTHLY VARIATION OF AMOUNT OF LOW CLOUD FROM MEAN OF THE YEAR (11 MONTHS).

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
1932	..	..	..	..	..	..	..	..	..	+3·2	+1·1	+0·2	
1933	−0·5	−1·7	−1·2	−0·6	+0·2	+1·1	−0·4	−0·6	..	..	..	..	3·5

TABLE 72.—MONTHLY VARIATION OF PERCENTAGE FREQUENCY OF CLEAR SKIES (0–1) FROM MEAN OF THE YEAR.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1882	..	..	..	..	..	..	..	..	−5	− 8	−7	+7
1883	+25	+ 2	+28	−1	+2	−13	−14	−17	..	..	..	..
1932	..	..	..	..	..	..	..	+ 9	+1	−15	−3	−1
1933	+20	+11	+ 6	−1	0	−13	− 6	− 6	..	..	..	..
Mean	+23	+ 7	+17	−1	+1	−13	−10	− 8*	−2	−11	−5	+3
Smoothed	+14	+13	+10	+4	−3	− 9	−10	− 7	−6	− 7	−5	+6

TABLE 73.—MONTHLY VARIATION OF PERCENTAGE FREQUENCY OF OVERCAST SKIES (9–10) FROM MEAN OF THE YEAR.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1882	..	..	..	..	..	..	..	..	−1	+33	+22	−4
1883	−16	−2	−20	0	−9	+5	− 5	− 3	..	..	..	..
1932	..	..	..	..	..	..	..	−22	+3	+23	+10	+3
1933	−11	−7	− 2	+5	−2	+7	−14	− 8	..	..	..	..
Mean	−13	−5	−11	+3	−5	+6	−9	− 9*	+1	+28	+16	−1
Smoothed	− 8	−9	− 6	−3	0	−1	− 5	− 7	+5	+18	+15	0

* August and September 1932 are based upon eight daily observations. The year is based upon thirteen months.

radiate to the clear sky above. In addition, the clouds will receive little heat from the sun and little from the ground, so that the conditions are quite suitable for their dispersion. These two conditions, an increase of convection clouds during the summer and a decrease of the thin clouds owing to loss of heat by radiation in the winter, will give an annual variation with a maximum in the summer and a minimum in the winter.

The annual variation during the year, however, shows a marked principal maximum in the late autumn, especially during the month of October. The cause of this principal maximum is more difficult to explain. When discussing the frequency of cloud forms it was seen that there was a marked increase in the frequency of the St and Stcu cloud forms during October and in the Nbst cloud form in November for the year 1932–33. Too much reliance cannot be placed upon the cloud forms during 1882–83 for reasons previously explained, although if we consider the St, Stcu, and Nb clouds of that year, there is a marked increase in the total frequency of these forms during October compared with that during September. The decrease in total frequency between October and the succeeding months is not so great however. The variation of the frequency of the Nb cloud form alone during that year does show a principal maximum in October, and an examination of the hourly values shows that the amount of Nb at each entry was generally ten. It would, however, be misleading to place too much reliance upon the cloud forms during 1882–83.

It is believed, therefore, that the principal maximum is closely connected with the increase in the cloud forms St, Stcu, and Nbst during October and November. This is not surprising, as these cloud forms, being the most frequent, usually covered the whole sky, and their variations would therefore govern the variations of the total cloud amount.

Now, when discussing the effect of the NW. or SE. type of wind upon the meteorological elements, and in particular upon the cloud amount, it was seen that the cloud amounts differed with the type of wind and with the seasons. For the sake of convenience the mean cloud amounts for the seasons and the wind types have been re-entered in Table 74. It is to be remembered that in this analysis only winds whose mean velocities during the day were greater than or equal to 4·0 m/s were considered. Likewise, a day of NW. wind was defined as a day during which the wind had for 18 out of 24 hours a direction between 236° and 34°; whereas a day of SE. wind was one during which the wind had for 18 out of 24 hours a direction lying between 56° and 214°.

TABLE 74.—THE EFFECT OF THE SOUTH-EASTERLY WIND UPON THE CLOUD AMOUNT IN THE AUTUMN ($\bar{V} \geqslant 4{\cdot}0$ m/s).

Season.	North-Westerly.		South-Easterly.		Weighted Mean Cloud.
	Mean Cloud.	Percentage Frequency.	Mean Cloud.	Percentage Frequency.	
Spring . .	7·2	38·9	5·6	35·9	6·4
Summer . .	7·3	34·3	5·6	42·8	6·4
Autumn . .	6·8	42·9	8·3	37·3	7·5
Winter . .	5·7	55·6	6·4	17·1	5·9

The table is of particular interest in showing the large increase in the mean cloud amount during the autumn for SE. winds compared with the other seasons for the same type of wind direction. The mean cloud amount for the SE. wind reaches the high figure of 8·3 compared with the next highest of 6·4 during the winter.

The NW. type produces a decrease in the cloud amount during the autumn compared with the spring and summer, but the amount is greater than the amount during the winter.

If reference be made to Table 43, showing the frequency of winds from the different directions for the seasons of 1932–33, the values from winds blowing from SW. to NE. have been grouped together as the NW. type, and the values from ENE. to SSW. have been grouped together as the SE. type. These values have been entered in Table 74, but it is to be noticed that they do not strictly give the frequency of the winds used in determining the mean cloud amount, as they contain cases where the wind from the respective directions was less than 4·0 m/s and cases where the wind from these directions was greater than 4·0 m/s, but which were not used in determining the mean cloud amount owing to the definition of a day of NW. or SE. wind. They will, however, give an approximate check on the effect of these winds upon the annual variation of the cloud amount. Assuming these frequencies of winds and the mean cloud amounts, weighted mean values of the cloud amounts have been determined, and they have been entered in Table 74. These weighted mean values have been plotted in the inset diagram of fig. 28. The effect of the large increase in the weighted cloud amount during the autumn is to give an annual variation with a minimum in the winter and a striking maximum in the autumn.

It appears therefore that the annual variation of cloud amount depends upon two main factors:—

(1) The increase of convection clouds during the summer, and the dispersal of thin clouds during the winter, owing to the loss of heat by radiation to the atmosphere. This would give an annual variation with a maximum in the summer and a minimum in the winter.

(2) The large increase in the amount of St, Stcu, and Nbst occurring with the SE. wind in October and November, which gives a striking maximum during the late autumn.

The combination of these two effects gives an annual variation of cloud with a principal maximum in October, a minimum in January and February, and a secondary maximum in June. There yet remains the difficulty of accounting for the increased frequency of St, Stcu, and Nbst during October and November and explaining why it should appear mainly with the SE. wind. A probable explanation is given in the section treating the annual variation of relative humidity.

5. DIURNAL VARIATION OF CLOUD

Observations of the amount of cloud were taken at the eight standard hours during August and September 1932, but the amounts of both total and low cloud were taken hourly, subject to the limitations previously mentioned, for the rest of the year.

The mean hourly values of the total and low cloud amounts for the months and the year are given in Table 19, Vol. II. The mean hourly values of the total cloud amount for the seasons of the combined years are given in Table 75.

The diurnal inequalities of the total and low cloud both for the months and the seasons, corrected for non-cyclic change, have also been entered in Table 20, Vol. II. The diurnal inequalities of total cloud amount, based upon hourly values taken in 1882–83, have not been published, but these values have been obtained and are entered in Table 21, Vol. II.

The inequalities of cloud amount for the two years have proved of great interest, and in order to facilitate the rest of the discussion these values have been represented in fig. 29, the inequalities for 1882–83 being kept distinct from those of total and low cloud during 1932–33.

If the monthly inequalities for 1882–83 be now examined it will be seen that for practically all months there are two maxima, one in the morning and one in the evening. The times of the maxima vary from one month to another. The only months which do not show the distinct maxima are the three months, May, June, and July, around the summer solstice.

If now the inequalities for the year 1932–33 be examined, it will be seen that both for the low cloud and the total cloud there are in general two maxima; but these maxima differ in their character from the maxima of 1882–83. In the first place, there is a principal maximum which in general occurs in the day; secondly, there is a secondary maximum which occurs shortly before midnight—generally speaking, from 19–22h. It may also be pointed out that this secondary maximum is more developed in the amount of low cloud than in the amount of total cloud. Another surprising difference between the two years is the fact that the secondary maximum is also well developed in the three months, May, June, July, around the summer solstice, particularly so in the amount of low cloud.

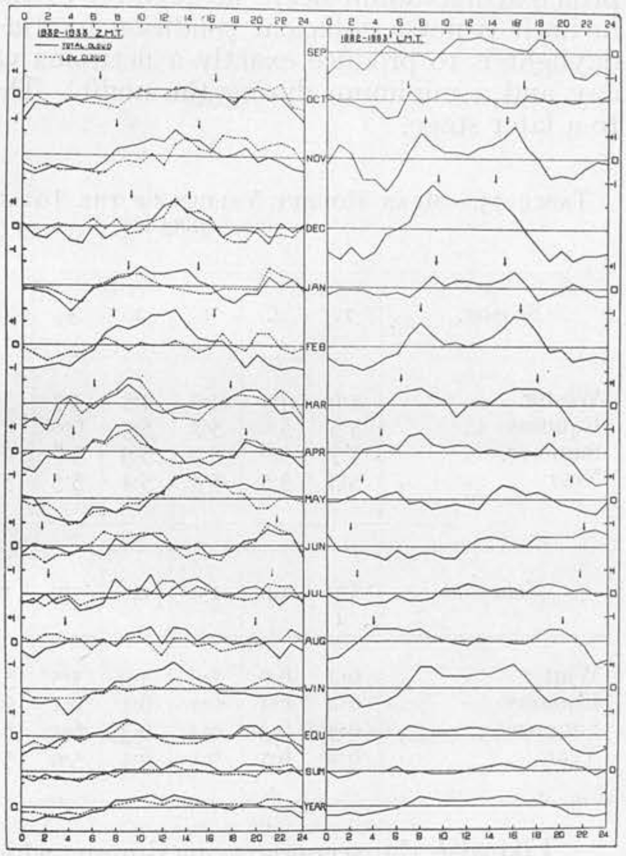


FIG. 29.—Diurnal inequalities of total and low cloud amounts.

Bearing these facts in mind, it will be well to refer now to Simpson's* discussion of the variation of cloud in the Antarctic. He states that ". . . the amount of daylight plays an important part in the estimate of the amount of cloud. If there was the same average amount of cloud throughout the day and night, the effect of the daylight would be to produce a fictitious daily variation having a maximum during the hours of daylight and a minimum during the hours of darkness." Simpson then proceeds to consider three periods: (*a*) periods when there is sufficient daylight throughout the 24 hours for the clouds to be clearly seen; (*b*) periods during which the sky is too dark for the clouds to be seen by the aid of the sunlight; and (*c*) periods during which there is daylight during part of the 24 hours and darkness during the remainder. Daylight cannot affect the periods (*a*) and (*b*), but Simpson shows, from a consideration of the Antarctic results and the *Fram* results, that the daylight appreciably affects the period (*c*). Sverdrup has also shown that the daylight affects the results of the *Maud*.

At Fort Rae the period is entirely that of (*c*), so that it will be well to investigate the effect of the daylight upon the daily variation. For this purpose the duration of sunlight for each month has been determined, the mean value for a month being considered as the duration of sunlight for the midday of the month. Account has been taken of the local mean time or the zonal mean time used during the respective years, and the apparent noon has been converted into the local or zonal mean time depending upon the year under consideration. The times of sunrise or sunset for both years have been marked by arrows pointing downwards in fig. 29.

Further examination of the inequalities for the year 1882–83 reveals the surprising feature that now the maxima of cloud in the nine months agree nearly throughout with the times of sunrise and sunset, *i.e.* with the change from darkness

* G. C. Simpson, *The British Antarctic Expedition, 1910–1913*, pp. 157–159.

to daylight or *vice versa*. This in itself makes one dubious of the results. Now this agreement between the maxima and the times of sunrise and sunset is not in evidence in the three months around the summer solstice. If the effect of the maxima coinciding with the times of sunrise or sunset was real, then it is surprising that it is not in evidence during at least one of the three months around the summer solstice. The duration of daylight is long, and apart from a period of about one hour during June the twilight is sufficiently strong to observe the clouds in detail.

If we revert now to the inequalities for the year 1932-33, in general, the principal maximum bears no relation to the times of sunrise or sunset; but this in itself is not a sufficient condition for the reality of the feature, as the effect of daylight is to produce exactly a fictitious variation having a maximum during the day and a minimum during the night. The reality of this feature we shall leave to a later stage.

TABLE 75.—MEAN HOURLY VALUES OF THE TOTAL CLOUD AMOUNT FOR THE COMBINED YEARS 1882-83, 1932-33 (23 MONTHS).

Season.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Winter	4·9	4·9	4·7	4·5	4·7	5·1	5·4	5·9	5·9	5·9	5·9	6·0
Equinox	5·5	5·6	5·7	5·9	6·0	6·1	6·3	6·5	6·5	6·4	6·2	6·2
Summer	5·7	5·8	5·9	5·9	5·8	6·0	5·9	6·1	6·0	6·0	6·2	6·1
Year	5·3	5·5	5·4	5·4	5·5	5·7	5·8	6·1	6·1	6·1	6·1	6·1

Season.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	Mean.
Winter	6·2	6·0	5·9	5·9	5·5	5·2	4·9	5·0	4·9	5·0	4·9	4·9	5·3
Equinox	6·2	6·1	6·1	6·1	6·1	6·3	6·4	6·3	5·7	5·5	5·5	5·3	6·1
Summer	6·3	6·3	6·3	6·3	6·1	6·2	6·3	6·3	6·2	6·0	5·9	5·9	6·0
Year	6·2	6·1	6·1	6·1	5·9	5·9	5·9	5·8	5·6	5·5	5·5	5·3	5·8

Likewise the secondary maximum, which occurs in general from 19-22h, bears no relation to the times of sunset. It is thought to be mere coincidence that they agree for some months owing to the lengthening of the day and the fact that the secondary maximum occurs in the interval 19-22h mainly. Furthermore, not only do these secondary maxima occur in the months May, June, and July, but they occur in spite of a probable fictitious variation tending to decrease the amount of cloud at night and acting therefore in the opposite sense. The evidence therefore seems to be in favour of regarding the secondary maxima both in total and in low cloud as a real effect.

In order to throw further light as to whether these features are to be regarded as real or spurious, the diurnal variation of the total cloud amount during days of new moon and during days of full moon have been determined for the four winter months November, December, January, and February of both years. For this purpose six days around new moon and full moon have been taken in each month, and the results of the inequalities have been plotted in fig. 30.

The results for 1932-33 are in striking disagreement for new moon and full moon. At new moon the effect of the varying daylight should be very great, whereas at full moon the moonlight should facilitate the estimate of the amount of clouds, and the contrast between the night and the day hours should be much smaller. This is exactly what we observe from the figure for the results of 1932-33 and to a lesser extent for the results of 1882-83.

But in spite of this, both during new moon and during full moon, there is still strong evidence in 1932–33 for the secondary maximum before midnight, and the evidence is even stronger in 1882–83. The agreement of the secondary maximum during full moon and during new moon is much closer in 1882–83 than even in 1932–33 where the effect was first noticed. The maxima agreeing with the times of sunset and sunrise for the year 1882–83 are still marked, but they are quite distinct from the maximum which occurs before midnight.

The only reliable result, therefore, that can be drawn from the diurnal variation of cloud is the fact that there is, during all months, a tendency for increased cloud at Rae shortly before midnight, this feature being more marked in the low cloud than in the total cloud.

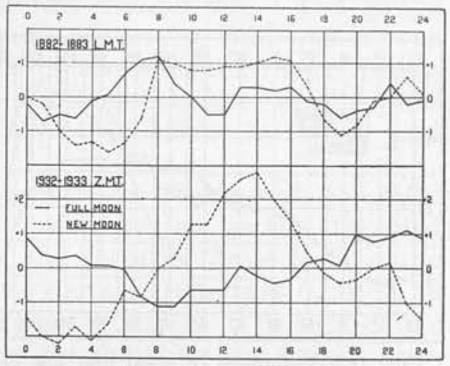


FIG. 30.—Diurnal inequalities of total cloud amount during new and full moon.

To members of the expedition who spent the year at Rae, this result will not be surprising, at least during the winter months. The effect of the increased amount of cloud, especially of the low cloud, did not strike the observers so markedly during the summer months, probably due in part to the continued daylight and in part to the fact that in the summer the low cloud was not accompanied generally by precipitation, but during the winter the low cloud brought very slight snow.

The character of the change was of the following nature:—

The day would start with a cloudless sky, but during the morning much thin Ci, Cist would appear, increasing in amount until at about noon the whole sky would be filled with thin Ci, Cist. During the afternoon the cloud would thicken and the cloud-sheet would become one of entirely thick Cist. It generally appeared that the thickening took place most rapidly one or two hours before sunset, but there is no definite evidence to support this statement. Around sunset, sometimes before and sometimes after, the thick Cist would appear to degenerate fairly rapidly into thick Ast, which continued degenerating into low Nbst by the evening, giving very slight snow in the winter months.

The changes in form during degeneration were in general much more complex than this, and they can best be represented by the following scheme:—

$$\left.\begin{array}{l}\text{Cicu}\\ \text{Ci}\end{array}\right\} \longrightarrow \left.\begin{array}{r}\text{Cist}\\ \text{Acu}\end{array}\right\} \longrightarrow \text{Ast} \longrightarrow \left\{\begin{array}{l}\text{Nbst or}\\ \text{Nbst and Stcu.}\end{array}\right.$$

This scheme represents the complete changes from the high cloud to the low cloud, but during degeneration the cloud forms did not invariably retain this order. At times the cloud forms appeared to skip a stage, such as the degeneration of Cist directly into Nbst, which gave very slight snow. It has, however, been mentioned that it is extremely difficult to be certain of a cloud form at night. This process of degeneration, though not fully appreciated at the time, was definitely remarked upon at Rae. There is no doubt as to the total amount of cloud on these occasions, as the sky was in general definitely overcast, though the same certainty cannot always be applied to the cloud form.

In order to bring into prominence this type of change, the months from October 1932 to May 1933 have been examined in order to obtain typical days when the degeneration extended from the high cloud to the low cloud. Days when intermediate stages occurred, such as the degeneration of Ci into Cist, Ci into Ast, Acu into Nbst, etc., have been excluded. Altogether there were 15 days, and the diurnal variations both in the total and low cloud amounts have been determined, and the values have been plotted in fig. 31. The scale on the left-hand side of the diagram refers to the total and low cloud amounts.

The curve for the total cloud shows the increase in the amount, which reaches its maximum at 13h and remains at this maximum until 21h. The curve for the amount of low cloud shows little cloud before noon, but thereafter the amount increases, increasing rapidly before 17h to reach its maximum at 21h. After 21h both the total and the low cloud amounts decrease.

Now it has been stated that during these changes the low cloud in the winter was frequently accompanied by very slight snow. The diurnal variation of the amount of precipitation during these days should therefore show the character of the change. Unfortunately, the fall of snow was most often too light to affect the records of the Hellmann-Fuess snow-gauge, so that the entries in the hourly values have no amounts given them, but merely the entry (∗), corresponding to the fact that snow fell but was at a rate of less than 0·1 mm. per hour. Instead of the amounts, the number of occasions of snowfall during the various hours can be used as a similar criterion, an hour in which snow fell being given one count. The number of occasions of precipitation during the various hours for the same 15 days have been counted, but here two days have been excluded entirely owing to the fact that the precipitation collected in the Hellmann-Fuess was believed at the time of observation to be due entirely to snowdrift. The 13 other days all show snow in the evening without any indication of snowdrift. Entries in the hourly values of precipitation, such as hoar frost or rime, have, of course, been excluded, as they are not relevant to the discussion. The number of occasions at the various hours for these days have also been entered in fig. 31, the number of occasions between 0h and 1h being plotted against the ½ hour, etc. The scale applicable to the number of occasions of snowfall is given on the right-hand side of the diagram.

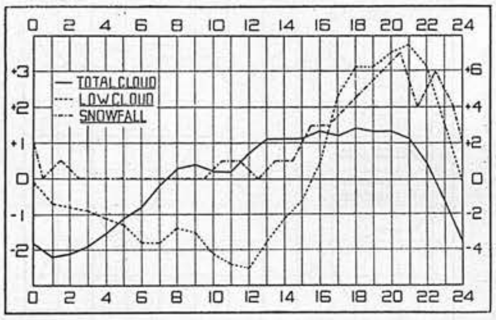


FIG. 31.—Variations of total and low cloud amounts and precipitation during selected winter days.

The curve of the frequency of precipitation has a striking agreement with the curve of low cloud.

All the preceding evidence appears to support the fact that at Fort Rae there is a tendency during all months for the cloud to increase during the evening hours, especially the amount of low cloud. The increase is probably caused by the degeneration of higher clouds into lower clouds, which give light snow during the winter months.

Whether this degeneration is a purely local effect or whether it is related to large scale movements in the atmosphere is difficult to determine. It is interesting to note, however, that the degeneration of the clouds, and in fact the whole sequence of cloud forms, is very similar to that which occurs with the advance of a depression. If this sequence of cloud forms is related to the advance of a depression, it would appear to signify that the incidence of a depression is more probable during the night than during the day. It is pertinent, therefore, to refer to a note by Douglas * on "The Deepening of Depressions by Day and Night," in which he favours the idea that there is a tendency for depressions to deepen by night. Professor W. J. Humphreys has also pointed out that depressions in the United States tend to deepen more by night than by day. From a consideration of the diurnal variation of barometric tendencies, however, Durst and Stanhope † do not find evidence to support this idea.

* C. K. M. Douglas, *Meteorological Magazine*, 66, pp. 39–41 (1931).
† Durst and Stanhope, *ibid.*, 69, pp. 184–185 (1934).

PART VII.—PRECIPITATION

I. INSTRUMENTS AND METHODS

(a) *Rain-gauge.*—A rain-gauge (8-inch funnel) of the standard pattern as described in the *Observer's Handbook* was erected with its rim 1 foot above the surface in the depressed ground near the Hudson's Bay Stores and Warehouse. The buildings were from 15 to 20 yards distant. The site chosen was a good one. The gauge was not too near the buildings to affect its exposure adversely, and yet it was sufficiently near to avoid being open to the full force of the wind. In fact, during the period when it was in operation it was sheltered from the full force of the wind in all directions, by rising ground to the W. and NW., by buildings to the N. and E., and by long reeds and rushes to the S.

The rain-gauge was read every morning at 8h and every evening at 20h, and the values obtained have been taken, during its period of operation, as the standard values of precipitation to which the curve values of the recorder have been made to agree. The periods to which these standard values refer are from July 6, 1932, to 9h October 6, 1932, and from 8h May 13, 1933, to August 31, 1933. The rain-gauge was in operation throughout the year, but the reasons for omitting the values from October 6, 1932, to May 13, 1933, will be dealt with when discussing the Hellmann-Fuess snow-gauge.

(b) *The natural siphon rain-gauge.*—The natural siphon rain-gauge (8-inch funnel) of the standard pattern described in the *Observer's Handbook* was erected 4 ft. distant from the rain-gauge. The instrument was, on the whole, a satisfactory instrument with which to work and gave an hourly record of the fall of rain. On one or two occasions, especially after a long spell of dry weather, there was a tendency for the siphon to dribble, but the defect could be immediately rectified by careful cleaning of the glass cover above the siphon chamber.

Owing to the danger of damage to the instrument occurring during the cold weather, it was brought indoors on October 6, 1932, and replaced again on May 13, 1933. During its period of operation the values obtained in the rain-gauge have been used as control values to the values recorded by the natural siphon rain-gauge. The hourly values of rainfall were read from the records of the natural siphon rain-gauge, and in general the totals for the periods 8–20h or from 20–8h agreed with the values as shown by the rain-gauge for these periods. Occasionally there were slight differences, and in such cases the hourly values from the natural siphon rain-gauge have been adjusted so that the totals during the periods agreed exactly with the values recorded by the standard rain-gauge for the same periods. The process was an easy one as all the differences were slight—of the order 0·1 to 0·2 mm.

(c) *The Hellmann-Fuess snow-gauge.*—In order to record the hourly values of snowfall during the winter a Hellmann-Fuess snow-gauge was set up near the site of the rain-gauge. The instrument is described in detail by Hellmann.*

The principle of the instrument is that the snow when it falls is collected in a large pan which rests on one arm of a balance, the other arm being weighted. As the snow increases in amount, the pan falls slightly, causing the other arm with the weights to rise, and this movement by a system of arms is magnified and recorded by the pen arm on the chart of a rotating clock suitably graduated. The collecting pan is protected at its collar by a Nipher's shield, which fits tightly in the opening of an outer circular cylinder forming the outer cover of the whole instrument. The instrument is large, standing about 5 ft. high, and presumably it is used in countries where the snowfall is heavy.

The instrument was not a satisfactory one with which to work for several

* G. Hellmann, *Met. Zeit.*, 23, pp. 337–339 (1906).

reasons. The zero line is set by the weights on the arm of the balance together with a fine adjusting screw which travels along the arm. But in the winter when the adjustment was made for the morning, the large changes in temperature which occurred during the day increased or decreased the effective moment of the weights, thus altering the zero. The amount was not much it is true, but when the snowfall, as at Rae, was very slight, frequently at rates much less than 0·1 mm. per hour, this variable error is quite large. Any fine adjustments outside in the cold are difficult to make.

Again, snow would frequently remain on the edge of the Nipher's shield without entering the pan at all, and the only record obtained was that obtained at the end, by scraping the snow off the shield into the pan. The very fine snow would also be driven under the Nipher's shield into the annular space between the collecting pan and the outer covering, thus preventing the free movement of the balancing system.

The 8-inch opening into the collecting pan is too large when the pan itself rests on a delicate balance, especially when winds begin to blow. The instrument then acts more like an anemometer than a snow-gauge, recording each gust and lull, so that the trace is blurred and mean values of the trace have then to be used. This inherent difficulty was appreciated when the instrument was set up at Rae. To avoid an increase in the surrounding eddies caused by its own bulk, it was decided to sink the instrument in a hole so that its orifice would be level with the ground. The island is covered practically entirely with granite rock, but near the site of the rain-gauge we were fortunate in being able to go to a depth of about 4 ft., and in this opening the Hellmann-Fuess snow-gauge was placed. Surrounding the whole site there was then erected a ring of cord wood about 1 ft. high and 12 ft. diameter, so that the orifice of the snow-gauge was fairly level with the top of the wood (Plate II (*c*)). This arrangement probably decreased the eddies in the neighbourhood of the Hellmann-Fuess, but during strong winds it still had a very thick trace caused by eddies.

Another defect lies in the fact that during even moderate winds the collecting pan has sufficient room to unbalance itself by the gusts and to rest either against the shield or the outer walls of the instrument, thus giving a spurious record.

These difficulties of an instrumental character can no doubt be overcome, and they are minor difficulties when compared with that of actually measuring the precipitation in the form of snow as distinct from that of drift. It frequently happens that, with a perfectly clear sky from which apparently no snow is falling, the wind raises loose snow from the ground in the form of drift, which enters the gauge and so gives a spurious record. In addition, it frequently happens that when snow is falling there is also an appreciable drift and the amount which enters the gauge bears no relation to the amount due to precipitation alone. This difficulty has not yet been solved, and it is, of course, the most important as regards the record of precipitation in the winter.

Furthermore, two sites very close to one another can show large differences in the amount of snowfall. This is quite evident from the values obtained from the rain-gauge when modified to collect snow and the values of the snow within the collecting pan of the Hellmann-Fuess. The sites were only a few feet distant, but the values bear no relation to one another, and it would be impossible to adjust the hourly values as shown by the record of the Hellmann-Fuess to fit the totals as obtained from the standard rain-gauge. Owing to this difficulty, another procedure had to be adopted for the winter months. The hourly values as obtained from the Hellmann-Fuess records have, during the winter months from 9h, October 6, 1932, to 8h, May 13, 1933, been adjusted so that the total precipitation during 24 hours commencing at 8h agrees with the measured snowfall inside the pan of the Hellmann-Fuess. In general these agreed, but at times, owing to the aforementioned difficulties, they did not.

It is thus seen that the hourly values given for the precipitation during the winter months is that recorded by the Hellmann-Fuess irrespective of whether the amounts are due to actual snowfall, drift, or snowfall and drift. These are the values entered in the tables of hourly values.

(d) *The hourly values.*—Tables are given in Vol. II showing for the 60-min. interval ending at the exact hour of zonal mean time the amount of precipitation, expressed in millimetres, derived from the records of either the natural siphon rain-gauge or the Hellmann-Fuess snow-gauge; the periods during which each has been used have already been given. Totals of amount are given for each day and for each month; the latter totals referring both to the complete days of the month and to each of the hours of the day. When zero rainfall or snowfall is assigned to a particular hour, the entry appears as "···" Corresponding totals of duration are also given, the duration being regarded as the number of hours during which rain fell at a rate of not less than 0·1 mm./hr. If slight precipitation, due to rain, snow, fog, or dew, extends over some hours, and if the amounts collected in some or all of the hours are less than 0·1 mm., the fact is indicated by a succession of entries, each of which is enclosed within brackets, covering the period over which the precipitation is known or believed to have occurred. In such cases entries of (0·1) are allocated evenly among the hours concerned in such a way that their sum is equal to the aggregate fall during the period, and the remaining entries are (···), (*), (≡), or (⌂) according as the precipitation took the form of rain, snow, fog, or dew. Slight precipitation which takes other forms such as hail, sleet, hoar-frost, and rime is dealt with similarly. When it is known or believed that the amounts collected are due to snowdrift entirely, the symbol ✢ is used in conjunction with the amount. Such values are enclosed in brackets. Similarly, when it is known or believed that the amounts collected are due to snow in the form of precipitation together with snow in the form of drift the symbol *✢ is used in conjunction with the amount. Such values are enclosed in brackets. In this manner an attempt has been made to separate partially, drift from true precipitation. When it is impossible to determine hourly amounts of precipitation, the normal procedure is to consider each case on its merits, and to derive hourly values from estimates based on the observations of the weather in the meteorological register. All such values are enclosed in brackets.

By the above method of entering the hourly values of snowfall, the precipitation due to snow, and to snow with drift, can be separated from that due to pure drift, and the results are modified for five of the six winter months. The following table gives a comparison of the amounts and the duration during the six winter months in the two cases:—

TABLE 76.—RECORDED MONTHLY PRECIPITATION INCLUDING AND EXCLUDING PURE DRIFT SNOW.

Form of Precipitation.	November.	December.	January.	February.	March.	April.	Total.
Snow; snow with drift; pure drift snow.	21·0 mm. 81·2 hr.	13·7 mm. 19·1 hr.	15·8 mm. 24·3 hr.	59·6 mm. 111·9 hr.	36·9 mm. 64·9 hr.	3·1 mm. 4·4 hr.	150·1 mm. 305·8 hr.
Snow; snow with drift.	19·2 mm. 77·2 hr.	11·2 mm. 14·8 hr.	15·8 mm. 24·3 hr.	15·4 mm. 44·3 hr.	20·6 mm. 43·3 hr.	2·8 mm. 4·4 hr.	85·0 mm. 208·3 hr.

The table shows that there are slight changes in the months of November, December, and April, no change in the quiet month of January, but very large changes in the months of February and March. The total of 85·0 mm. with a duration of 208·3 hours is a much better representation of the precipitation during the winter months than is obtained from the hourly values of the Hellmann-Fuess alone. These values in themselves probably exceed the true precipitation by at least 10 to 20%.

2. ANNUAL VARIATION OF PRECIPITATION

If the hourly values of precipitation as taken from the records be considered as the total precipitation for the year, then for the period of 14 months from July 1932 to August 1933 the total amount is 455·2 mm. with a duration of 575·3 hours. As it has been shown that the modified values for the winter months will give a better representation of the precipitation, these modified values will therefore be accepted. Thus for a more suitable estimate of the amount of precipitation during the six winter months, the recorded value should be multiplied by the factor 0·57. This factor will now be applied to the six winter months in the year 1882–83, and though the results will not give the exact precipitation they will undoubtedly give a much better idea of the true total amounts of precipitation.

The results of the calculation and the modified results for Fort Rae are entered in Table 77.

TABLE 77.—ANNUAL VARIATION OF PRECIPITATION.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
1882 . .	..	..	..	..	..	..	..	..	10·9	25·7	15·9*	8·2*
1883 . .	2·8*	10·9*	0·5*	2·2*	6·0	14·3	18·8	30·6	..	..	..	..
1932 . .	..	..	..	..	..	..	21·8	25·8	27·7	10·8	19·2*	11·2*
1933 . .	15·8*	15·4*	20·6*	2·8*	53·2	22·1	51·9	91·8	..	..	..	..
Mean . .	9·3	13·1	10·5	2·5	29·6	18·2	27·9 †	58·8 †	19·3	18·3	17·5	9·7

* These values have been modified in order to exclude pure drift snow as far as possible.
† The mean determined by Mean $= \frac{1}{2}[83 + \frac{1}{2}(32 + 33)]$.

The table shows that the precipitation varies greatly from year to year, but in both years the maximum precipitation occurred in the month of August and the minimum in one of the spring months, March or April. There appears also to be a small secondary maximum in February or March in both years, but it is doubtful whether any general characteristics of the annual variation can be drawn from the two years' data.

3. SNOW CRYSTALS

In accordance with the desires of the International Commission for the Polar Year,* observations upon the form of snow crystals during precipitation were carried out as frequently as possible during the winter, from October 1932 to May 1933.

As far as possible, the observations were not made when there was a heavy drift, owing to the fact that any sample then obtained would not be truly representative of the precipitation at the time. There were occasions, however, when there was drift snow only in the immediate layer close to the ground, and in such cases samples of the falling snow were examined. Such cases have been entered in the analysis, and the snowdrift symbol added to indicate the existence of the snowdrift.

The data have been entered in four columns in Table 22, Vol. II. In the first and second columns have been entered the date and time of the observation; in the third, the cloud from which the snow was believed to be falling; in the fourth, the forms of the snow crystals according to the symbols recommended by the International Commission.

The proportion in tenths of each form in any sample, together with the approximate estimated lengths of each form of crystal, has also been entered in the fourth

* Secretariat de l'organisation Météorologique Internationale No. 17. Annexe L. Instructions sur l'observation des diverses formes de neige. (1934.)

column. Anyone who has examined samples of snow under Arctic conditions will realise how difficult it is to describe in detail the various forms that do exist, the small and large differences that exist between various star-shaped crystals, the various degrees of transparency and hardness, etc. The following analysis is not an attempt to do this, but mainly to classify generally the snow crystals according to the international recommendations.

It will be seen in the classification that small grains or granules frequently occurred throughout the winter months. In all cases they were soft but very small, generally 0·5 to 1·0 mm. in diameter. At times they would have beautiful radial needle extensions, but along the axis of the needle and transverse to it there would be a large number of "feathers." At 9h on March 29, 1933, a sample showed isolated small granules similar in structure to those which had fallen throughout the winter apart from the extensions. At 9h 30m the sample showed all soft hail 2 to 3 mm. diameter but of similar structure to the small granules at 9h. It is thought, therefore, that the small granules which continued throughout the winter might be classified as soft hail, but of very small size. The only doubt which arises is due to the fact that on all days of heavy drift any sample always showed 9/10 to 10/10 small granules, though a sample taken at random from the surface during calm weather would still show a large variety of crystals.

PART VIII.—RELATIVE HUMIDITY OF THE AIR

1. GENERAL

The relative humidity of the air during 1932–33 was recorded continuously by means of a weekly hair hygrograph placed in the Stevenson screen. Complete details of the instrument can be obtained from the *Observer's Handbook*.

The values of the humidity at the standard observational hours, as obtained from the wet and dry bulb thermometers in the same screen, served as control values for the hygrograph records. In addition, a further control was obtained by using the Assmann psychrometer outside the screen at the 14h observations. This method of using controls for the hygrograph records was not satisfactory during the winter, because at low temperatures the temperature difference between the wet and dry bulbs became too small to read with any accuracy. In addition, the sensitiveness of the hygrograph was extremely small during the cold winter months. Consequently, the wet bulb temperatures were discarded during the winter months, so that for this period no control values exist. The hourly values of humidity for the months November to March inclusive are therefore of small value, but we shall discuss at a later stage the degree of accuracy of the mean monthly values obtained from the hygrograph during these winter months.

In order to determine the corrections applicable to the hygrograph, hourly values were read from the records, use being made of the daily time marks. The humidity was also computed for each standard observation from the readings of the wet and dry bulb. The difference between the humidity at an observational hour and the hygrograph value at the corresponding hour was then determined. The range of hygrograph values from zero to 100 was divided into subranges from 20 to 29, 30 to 39, . . ., 80 to 89, 90 to 100, and the differences (Humidity–Hygrograph value) were entered in the subrange appropriate to the corresponding hygrograph value. The mean of these differences in each subrange gave the correction to be applied to the hygrograph value in the various subranges.

As regards the hourly observations of humidity during 1882–83 no information is given in the results of the expedition as to whether these hourly values refer to the readings of the wet and dry bulb thermometers or to the readings of a hair hygrometer. It is known, however, that hourly readings of the wet and dry bulb thermometers and the hair hygrometer were taken, but it has been left to the reader to determine which values have been used in the hourly tabulations. A probable clue is given by the fact that at the head of each table is given the height of the thermometers above the ground. If, therefore, the wet and dry bulb thermometers have been used, the values for the winter months are extremely good for such readings, in view of the fact that during 1932–33 the temperature difference between the wet and dry bulb thermometers became too small in the cold months to read with any degree of accuracy. During 1882–83, however, the wet and dry bulb thermometers may have been used throughout the year as controls for the hair hygrometer and the hygrometer values may have been published.

2. MEAN MONTHLY VALUES OF HUMIDITY DURING THE WINTER MONTHS

It has been stated that there were no control values during the winter months of 1932–33, and this fact, together with the small sensitiveness of the hygrograph, make the hourly values very unreliable. At frequent intervals the hygrograph was brought indoors, cleaned and reset at temperatures of about 10° C. to 15° C. These settings would not necessarily be correct at temperatures of as low as −30° C. to −40° C., and there was no means of ascertaining whether they were correct within such large changes of temperature.

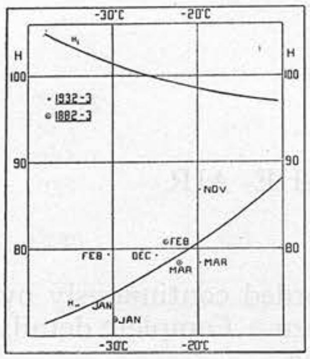


FIG. 32.—Observed relations between temperature and relative humidities over ice (H_i) and over water (H_w).

It will, however, be interesting to inquire into the degree of accuracy of the mean monthly values as obtained directly from the hygrograph records during the winter months of 1932–33 and for the published values for 1882–83. In this connection, therefore, it will be necessary to refer to the work of Malmgren on the *Maud* Expedition. In order to determine the relative humidity at low temperatures Malmgren * constructed a thermo-psychrometer by means of which, in the winters of 1923–25, he took a series of measurements. The thermo-psychrometer was an Assmann psychrometer from which the ordinary thermometers had been removed and replaced by two batteries of thermo-couples. By means of his thermo-psychrometer Malmgren was able to measure the humidity with an accuracy of ± 2% at a temperature of −40° C., an accuracy not yet attained by any other method at such low temperatures.

From his results with the thermo-psychrometer Malmgren "has shown that in the cold months the mean monthly values of the humidity can be derived from the mean monthly temperature, using the relation between the relative humidity and the temperature which his observations had given." † This statement is very remarkable.

The relation between the temperature and the relative humidity over water, H_w, which Malmgren obtained has been represented in fig. 32. The figure also includes the relation between the temperature and the relative humidity over ice, H_i, defined such that $H_i = \frac{100e}{E_i}$, where "e is the actual tension of the water-vapour and E_i the tension of water over ice at the observed temperature."

Now, if the mean monthly values of the relative humidity with respect to water, as obtained from the hourly values of the hair hygrograph during the winter months at Fort Rae and as obtained from the published values for Old Fort Rae, are accurate,

* Finn Malmgren, (1) "Studies of Humidity and Hoar Frost over the Arctic Ocean," Oslo, *Geof. Publ.*, 4, No. 6 (1926). This publication gives full details of the thermo-psychrometer used. (2) "On the Properties of Sea Ice," Bergen, *The Norwegian North Polar Expedition with the "Maud," 1918–25*, vol. i, No. 5 (1928).

† H. U. Sverdrup, Bergen, *The Norwegian North Polar Expedition with the "Maud," 1918–25*, vol. ii.

then the points for each month, which are defined by the mean temperature and the mean relative humidity, will not depart much from the curve H_w in the figure.

Table 78 contains the observed mean monthly values of temperature and humidity at Rae for November to March in both years, together with the values of the relative humidities computed from the Malmgren curve, which uses only the mean temperatures. The observed mean values of humidity have also been plotted against the mean temperatures in the figure.

TABLE 78.—MEAN TEMPERATURES AND HUMIDITIES DURING THE COLD MONTHS.

	1932–33.				
Month . .	November.	December.	January.	February.	March.
Temperature, °C. . .	−19·8	−24·9	−31·1	−30·5	−19·6
H_w observed, % . .	86·9	79·2	74·2	79·4	78·3
H_w computed, % . .	80·8	77·8	74·5	74·8	80·8
(H_w obs. − H_w comp.) . .	6·1	1·4	− 0·3	4·6	− 2·5
	1882–83.				
Temperature, °C. . .	−12·6	−26·2	−32·7	−23·6	−22·1
H_w observed, % . .	66·4	87·2	71·9	80·9	78·3
H_w computed, % . .	86·0	77·0	73·6	78·5	79·3
(H_w obs. − H_w comp.) . .	−19·6	9·8	− 1·7	2·4	− 1·0

An examination of the table shows that the agreement is exceedingly good except for the two months November and December 1882, and these two months have not been plotted in the figure.

It seems, therefore, that although the actual hourly values are unreliable, yet the mean monthly values of the humidity during November to March 1932–33 and during January to March 1883 are fairly accurate determinations. The values for November and December 1882 will therefore be discarded from any further consideration.

3. ANNUAL VARIATION OF THE RELATIVE HUMIDITY

In order to discuss the annual variation, the relative humidity with respect to water H_w will be retained for each month, in spite of the fact that this value has no meaning during the winter months.

Table 79 contains the mean monthly values of the relative humidity during the two years as deduced from hourly hygrograph records during 1932–33 and from the published values during 1882–83.

TABLE 79.—MEAN MONTHLY VALUES OF THE RELATIVE HUMIDITY H_w.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1882 . .	..	..	..	..	..	..	..	..	77·5	83·6	—	—
1883 . .	71·9	80·9	78·3	71·3	69·6	69·9	66·2	75·4	..	..	..	..
1932 . .	..	..	..	..	..	..	68·7	76·6	77·9	84·0	86·9	79·2
1933 . .	74·2	79·4	78·3	71·5	76·5	71·5	68·8	74·5	..	..	..	..
Mean . .	73·1	80·1	78·3	71·4	73·1	70·7	67·5*	75·5*	77·7	83·8	86·9	79·2

* Mean $= \frac{1}{2}[83 + \frac{1}{2}(32 + 33)]$.

The mean values for the corresponding months of both years agree exceedingly well with one another, the greatest difference being one of 6·9% in May.

The mean values for the months have been plotted in fig. 33, and the points have been joined together by a smooth line. In addition, instead of considering the observed values during the months November to March, the values computed from the curve H_w have been taken and means determined for these months of the two years. These values have also been entered in the figure, and the smooth curve has been joined to the computed values by a dotted curve.

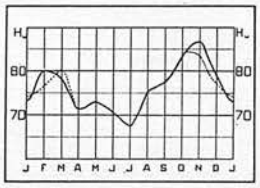


FIG. 33.—Annual variation of the relative humidity H_w.

Whichever curve be considered as the better representation of the annual variation, the general character of the curve remains the same. The relative humidity shows a minimum in the summer month of July, and there is a principal maximum in the late autumn, October to November, with a secondary maximum in February or March.

The fact that the annual variation shows a principal maximum in October or November is interesting and may give some explanation of the principal maximum of cloud amount which occurs in October. When considering cloud, it was seen that the principal maximum of the St and Stcu cloud forms, and of the amounts of total and of low cloud, occur in October. The increase in the cloud amount of St and Stcu occurs mainly with the SE. wind. Now, October is the first month in which sub-zero centigrade temperatures are recorded, and it is also the last month in which open water exists in the Slave Lake and its northern arm, which lies mainly to the south and south-east of Rae. The cooling of the lower layers of moist air above the surface of the water in the lake, below its dew-point, would in general give rise to wet fog, which, with the prevailing SE. wind, would be driven over Rae either in the form of wet fog, low St, or Stcu. There are no observations as to the frequency of fogs over the lake, but on three days during which wet fog occurred at Rae two occurred during October and one during May. Thus two days of wet fog occurred during the "freeze-up" and one during the "break-up," when there was a large extent of open water and when the temperatures were around or below zero centigrade.

It may also be noted that the principal maximum in October or November agrees with the period of "freeze-up," while there is also indication of a tertiary maximum occurring in May, the period of "break-up."

4. DIURNAL VARIATION OF RELATIVE HUMIDITY

As the hourly values of relative humidity are unreliable for the months November to March inclusive, these months have been excluded in the determination of the inequalities. Table 23, Vol. II, gives the diurnal inequalities for the remaining months of the year.

The inequalities are quite regular, showing positive values in the night and negative values in the day.

PART IX.—SUNSHINE AND RADIATION

The duration of bright sunshine at Fort Rae was measured by means of the Campbell-Stokes sunshine recorder. A full description of the instrument is given in the *Observer's Handbook*.

In order to obtain a good exposure two sites were in use during the year. The first, the summer site, was near the centre of the small island at a point marked D in the plan (p. 5); the second, the winter site, was near the Hudson's Bay dwelling-house at a point marked S in the plan. The summer site was in use from July 2, to noon October 13, 1932, and from noon April 13 to August 31, 1933; the winter site was in use during the remaining period. At the summer site the recorder was erected upon a metal cylinder (4 ft. 6 in. high), which was rigidly fixed to the rock by cement. When the recorder was removed in October the cylindrical support was left at the site, and the recorder was then erected on a stout tree trunk (4 ft. 5 in. high) made rigid by a cairn of stones placed around. The two sites proved quite satisfactory.

Care had to be taken during the winter months to prevent a loss of record in the early hours of daylight, owing to the formation during the night of hoar frost, etc., on the bowl of the recorder. In order to prevent this loss it was customary at Fort Rae to bring the sunshine bowl indoors after sunset and to place it back again a short time before sunrise. The observer on watch would later visit the recorder to see whether or not hoar frost, etc., had formed on the bowl after the morning setting. This procedure proved quite satisfactory during the winter months.

Solar radiation measurements were made with a Michelson actinometer within half an hour of apparent noon on all suitable days. The conditions of the intervening atmosphere during the observations are indicated in the tables in the column headed "sky." The Michelson actinometer had previously been calibrated in February, March, and April against the Ångström pyrheliometer No. 24 at Kew Observatory. The results of the comparison showed that the Michelson values should be multiplied by 1·41 in order to be comparable with the Ångström values. This factor has been applied to all the readings taken at Fort Rae, and the amount of radiation has been entered in gm. cal./cm.²/min. in the column headed "Total." The vertical component of the direct radiation received per sq. cm. of horizontal surface has also been given. In order to bring the readings into accordance with the scale adopted by the Smithsonian Institution a correction of +3·5% would be required.

PART X.—HALO PHENOMENA

Halo phenomena were very frequent at Fort Rae especially during the winter and spring months. The phenomena seen conform to the types given in Pernter's *Meteorologische Optik*. Those enumerated below and represented in fig. 34 are the most interesting of those seen during the year.

(1) 5h, 7 March 1933. Three mock moons on the horizon all 10° below the level of the moon, the two outer ones apparently at a position on the 22° halo. A moon pillar extended from the moon to the central mock moon, with two weak moon pillars above the outer mock moons extending to an elevation of about 5°. Whitish colouration.

A similar phenomenon occurred with the sun a short time after sunrise on January 24, 1933. The outer sun pillars, however, did not exist.

(2) 8h, 4 November 1932. Two mock suns, brightly coloured with red on the inner edge and green on the outer edge. An orange-red sun pillar extending upwards to an elevation of about 10°.

Variants of this phenomena occurred frequently throughout the year.

(3) 19h, 28 April 1933. A faint upper and lower sun pillar, orange-red colouration, occurred at the same time, a little before sunset. This phenomena occurred only once during the year.

(4) 11h, 30 April 1933. The 22° halo with both upper and lower arcs of contact, concave to the sun. Whitish colouration. Parts of this halo occurred frequently throughout the year.

(5) 10h, 19 August 1933. A brilliant halo complex consisting of the 22° halo, the upper and lower arcs of contact, the mock sun ring, three mock suns, part of the 46° halo, lateral arcs of contact, and an inner non-circular ring. After 10h 5m

the inner ring developed into two oblique arcs meeting at a point *a* in the anthelion and meeting the 22° halo at *cc*. The brilliant colours seen are given in the diagram.

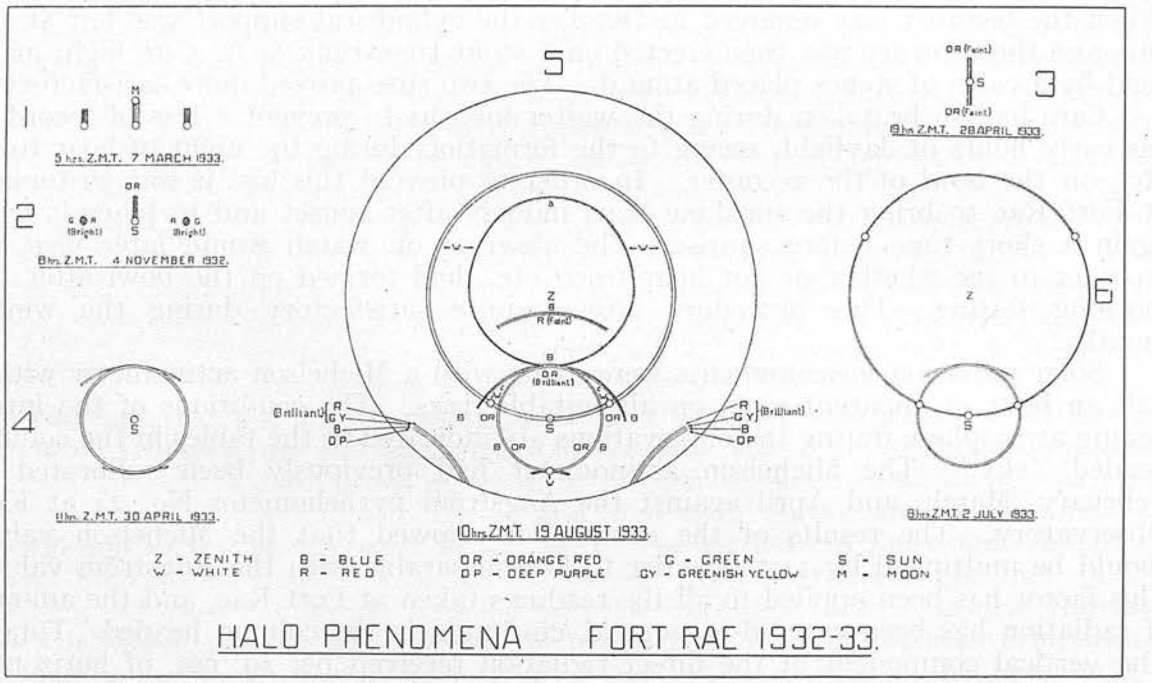


FIG. 34.

(6) 8h, 2 July 1933. The 22° halo, upper arc of contact, the mock sun ring, four mock suns, two on the 22° halo and two at 120° from the sun. Whitish colouration.

Parts of this halo, excluding the 120° mock suns, were frequently seen during the year.

PART XI.—VISIBILITY

The system of observations of visibility was that comprised in the *Meteorological Observer's Handbook*, objects being selected as nearly as possible at the specified distances from the point of observation, and the farthest visible object was noted at each observation hour. The farthest visible object of known distance was a mountain in the north, called "Island Mountain" by the party, owing to its appearance of rising directly as an island from the body of the lake. On very clear days, however, the summit of another mountain slightly to the east of Island Mountain, together with the summits of mountains due east, were just visible. These mountains are not marked on the maps and no distances are available. When these were visible, object M was entered in the register. When, also, the features of Island Mountain and its surface were visible in great detail, although the unnamed mountains were still not visible, object M was entered in the register.

The actual distances and the standard distances of the visibility objects are entered in Table 80.

Table 81 shows the percentage frequency of occurrence of the different grades of visibility in the various months. The results are based upon the standard observations made eight times daily.

The outstanding feature of the table is the large proportion of good visibilities recorded during all the months of the year. From April to August 1933 the proportion of visibilities M is exceedingly high. The occurrence of fog, visibility E or lower, was particularly rare as seen from the percentages in the table. In fact, if the visibilities E or lower are considered in further detail they are associated entirely with drift snow during November and February, with fog during September, October, May, and June; and in December 0·4% is attributable to fog and 0·8% to drift snow.

TABLE 80.—DISTANCES OF VISIBILITY OBJECTS AT FORT RAE.

Object.	Standard Distance.	Actual Distance.	
A	27 yards	27 yards	
B	55 ,,	55 ,,	
C	110 ,,	112 ,,	Fog
D	220 ,,	221 ,,	
E	550 ,,	523 ,,	
F	1100 ,,	1450 ,,	
G	$1\frac{1}{4}$ miles	$1\frac{1}{4}$ miles	
H	$2\frac{1}{2}$,,	$2\frac{3}{4}$,,	
I	$4\frac{1}{3}$,,	$4\frac{3}{5}$,,	
J	$6\frac{1}{4}$,,	No suitable object	
K	$12\frac{1}{2}$,,		
L	$18\frac{2}{3}$,,	$18\frac{2}{3}$ miles	
M	31 ,,	Mountains unknown, but distance greater than 31 miles	

TABLE 81.—PERCENTAGE FREQUENCY OF OCCURRENCE OF DIFFERENT GRADES OF VISIBILITY AT FORT RAE, 1932–33

Combined Observations at 2h, 5h, 8h, 11h, 14h, 17h, 20h, 23h

Visibility Grade.	1932.					1933.							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
A	..	..	..	..	..	..	0·4	..	..	..	..	..	..
B	..	..	..	..	..	..	..	..	..	..	..	..	..
C	..	0·4	0·8	0·8	..	..	0·4	..	..	..	..	..	..
D	..	..	0·4	..	0·8	..	0·4	..	..	1·6	..	..	..
E	..	..	0·8	0·4	0·4	..	0·9	..	..	..	0·8	..	..
F	..	..	1·6	0·4	2·4	4·0	5·3	0·8	1·7	0·8	..	..	..
G	1·2	..	1·2	3·7	3·6	2·8	2·2	1·6	5·0	1·6	..	..	1·6
H	0·8	1·3	5·6	9·2	4·1	3·2	3·1	1·6	0·4	0·8	..	1·2	0·4
I	3·2	3·3	13·7	11·3	4·1	2·8	3·7	4·0	0·8	5·2	1·3	2·4	2·0
J	4·5	5·4	5·7	9·2	7·7	5·6	10·3	7·3	0·8	5·6	0·4	1·6	0·4
K	1·6	2·1	3·2	7·1	19·0	11·3	16·9	14·9	2·1	0·8	0·8	3·2	1·2
L	67·2	53·1	52·8	41·3	44·5	51·3	43·8	44·3	31·3	24·6	18·3	9·3	13·3
M	21·5	34·3	14·1	16·7	13·4	19·0	12·6	25·4	57·9	58·9	78·4	82·3	81·0

PART XII.—THE METEOROGRAPH DIAGRAMS

The complete variations of temperature and pressure throughout the year from 1932 August 1 to 1933 August 31 have been plotted against time from the corrected hourly values of those elements published in the tables. The points so obtained have been joined by lines which give an exact representation of the course of temperature and pressure between the hours, as shown by the actual records of these meteorological elements. The curves are represented in figs. 35 to 41 inclusive. The thicker and more steady curve is the pressure curve which has been corrected for index error, temperature, and latitude, and has been reduced to station level. The thinner and more variable curve is the temperature curve.

At each standard observational hour, wind force in the Beaufort scale is indicated by the number of feathers on the arrows, which are oriented in the conventional manner, a N. wind from the top to the bottom of the diagram, a W. wind from left to right, etc.; o indicates calm.

Likewise at each observational hour, weather phenomena such as rain (●), snow (∗), hail (▲), fog (≡), mist (≡°), dew (⌓), drift snow (+), etc. have been represented by the appropriate international symbols the intensity being characterised by a suffix 0 or 2 in the usual manner. Observations of solar or lunar halos or coronæ have been omitted as their frequent representation might mask the utility of the diagram. Likewise, observations of aurora have been omitted entirely as they are fully treated elsewhere. The weather diary given in Beaufort letters for three-hourly intervals between the standard hours of observation should be used in conjunction with the "meteorograph" diagrams. The diary gives the details of the halo and corona developments during the year.

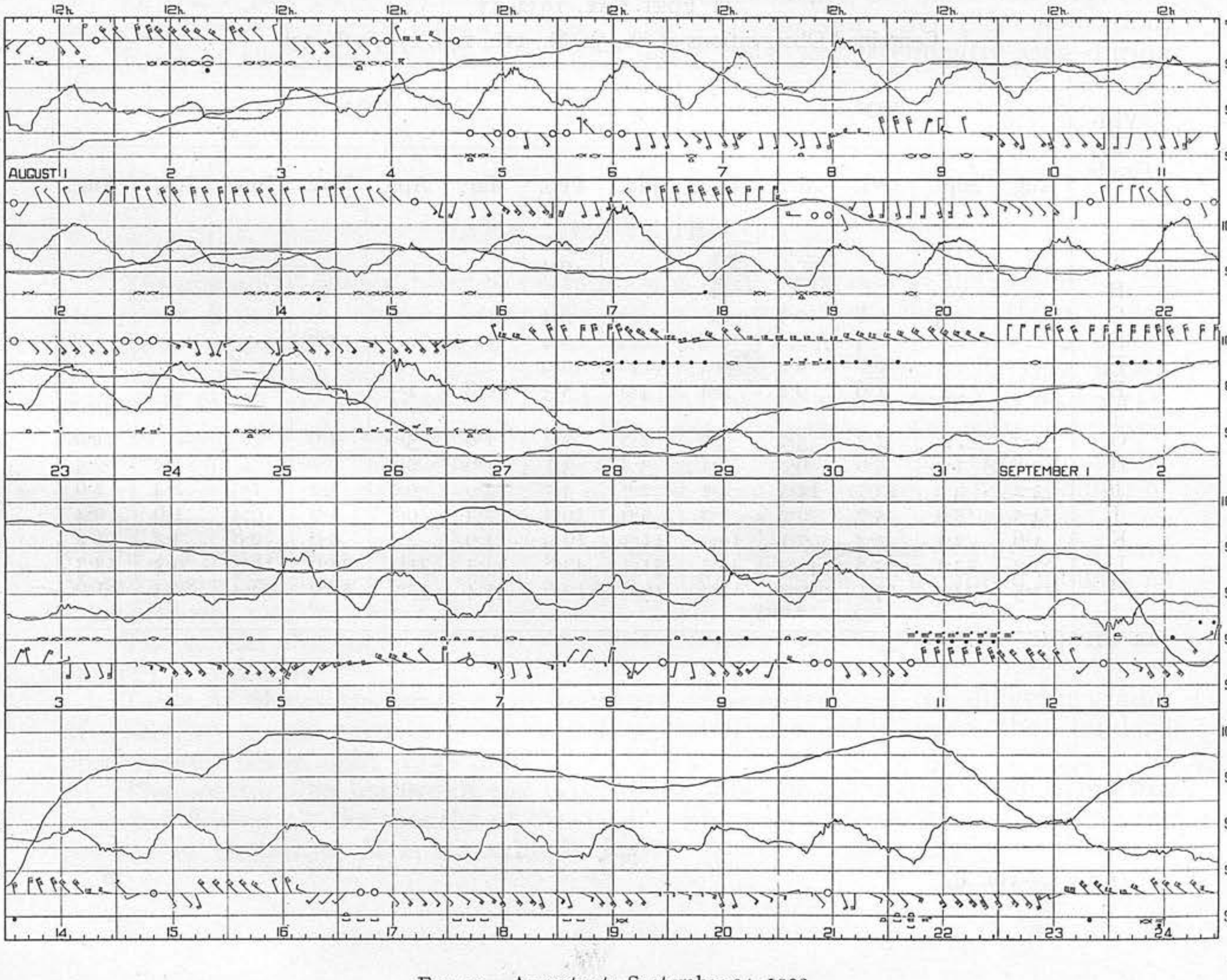


FIG. 35.—August 1 to September 24, 1932.

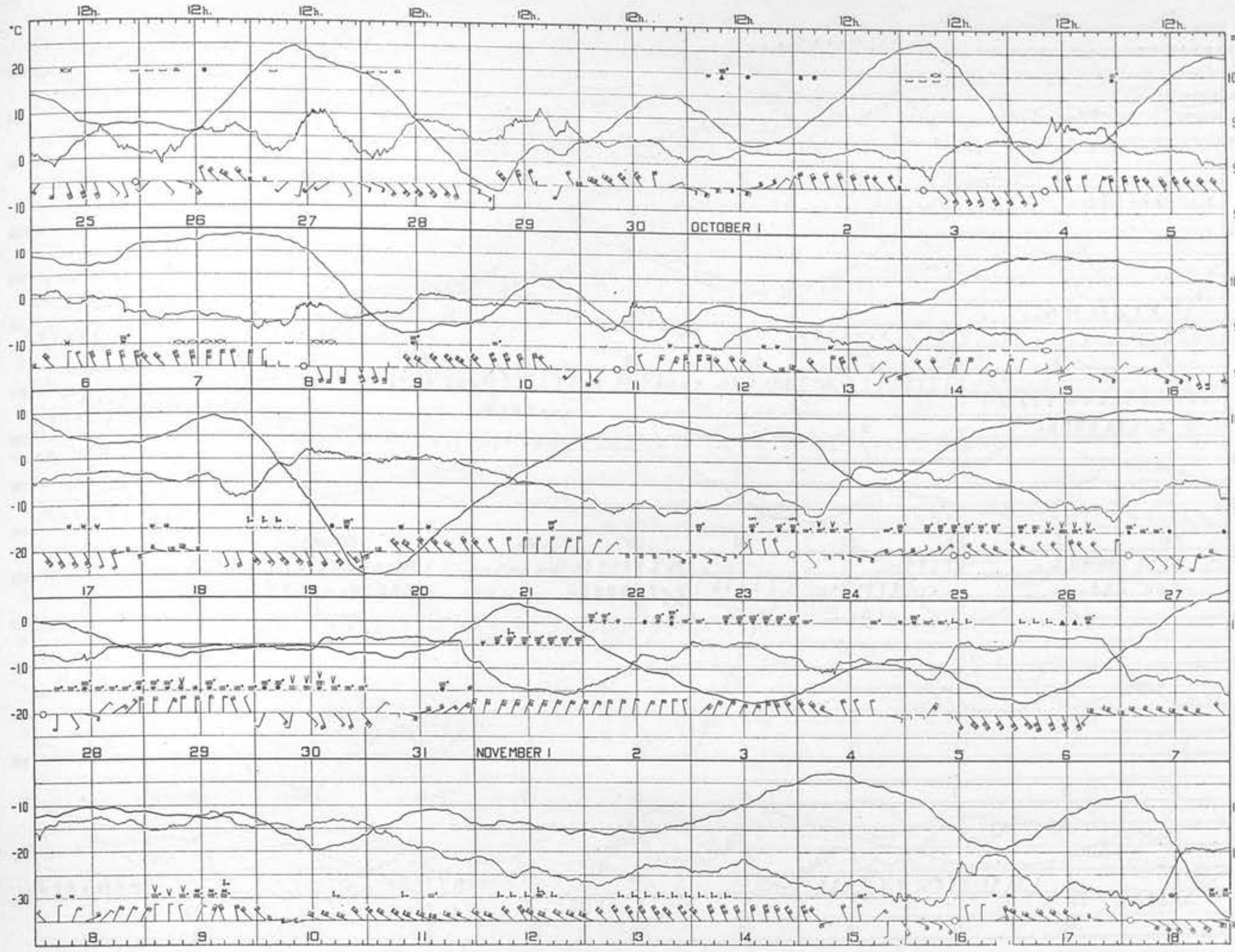


FIG. 36.—September 25 to November 18, 1932.

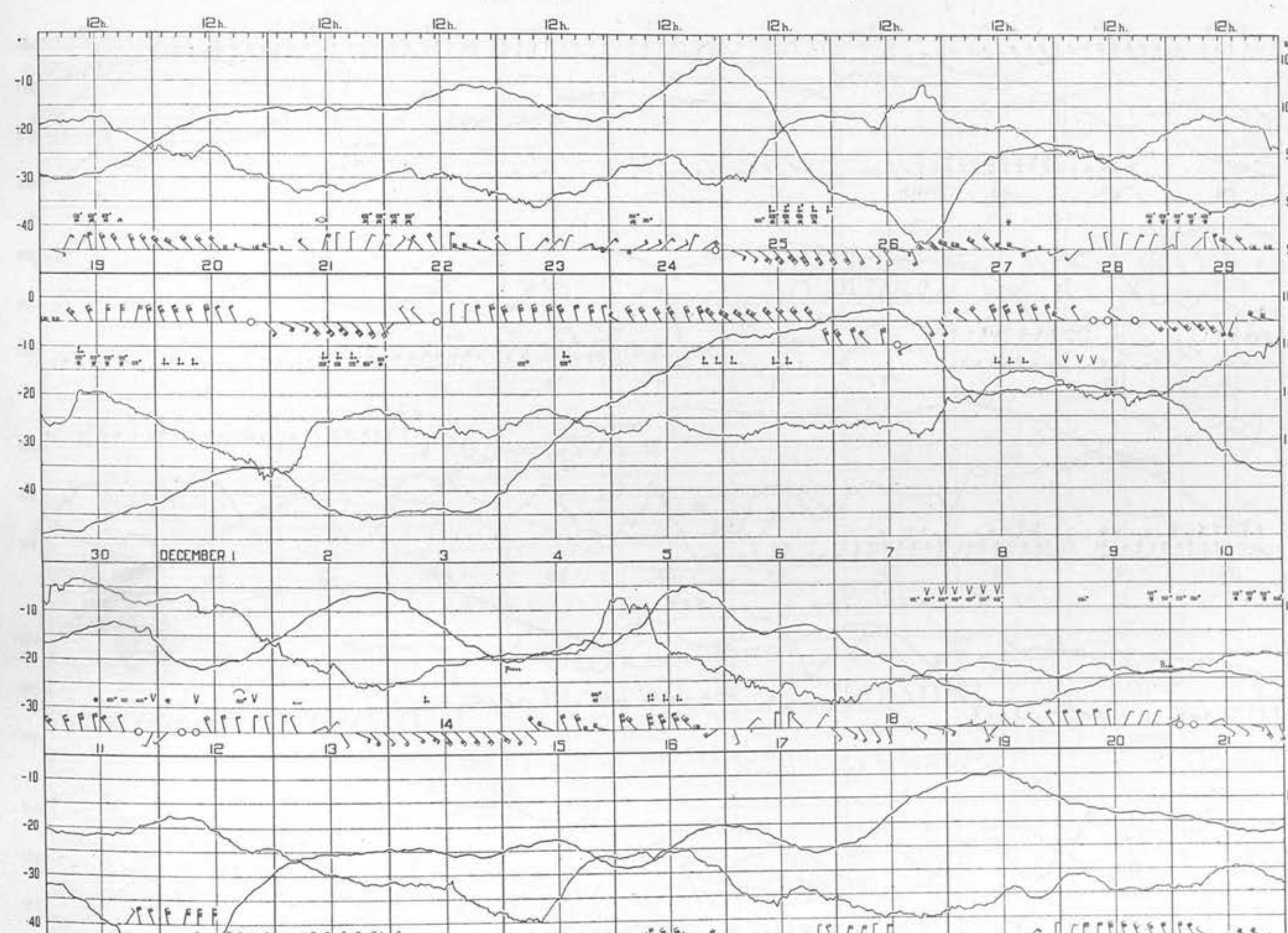


FIG. 37.—November 19, 1932, to January 1, 1933.

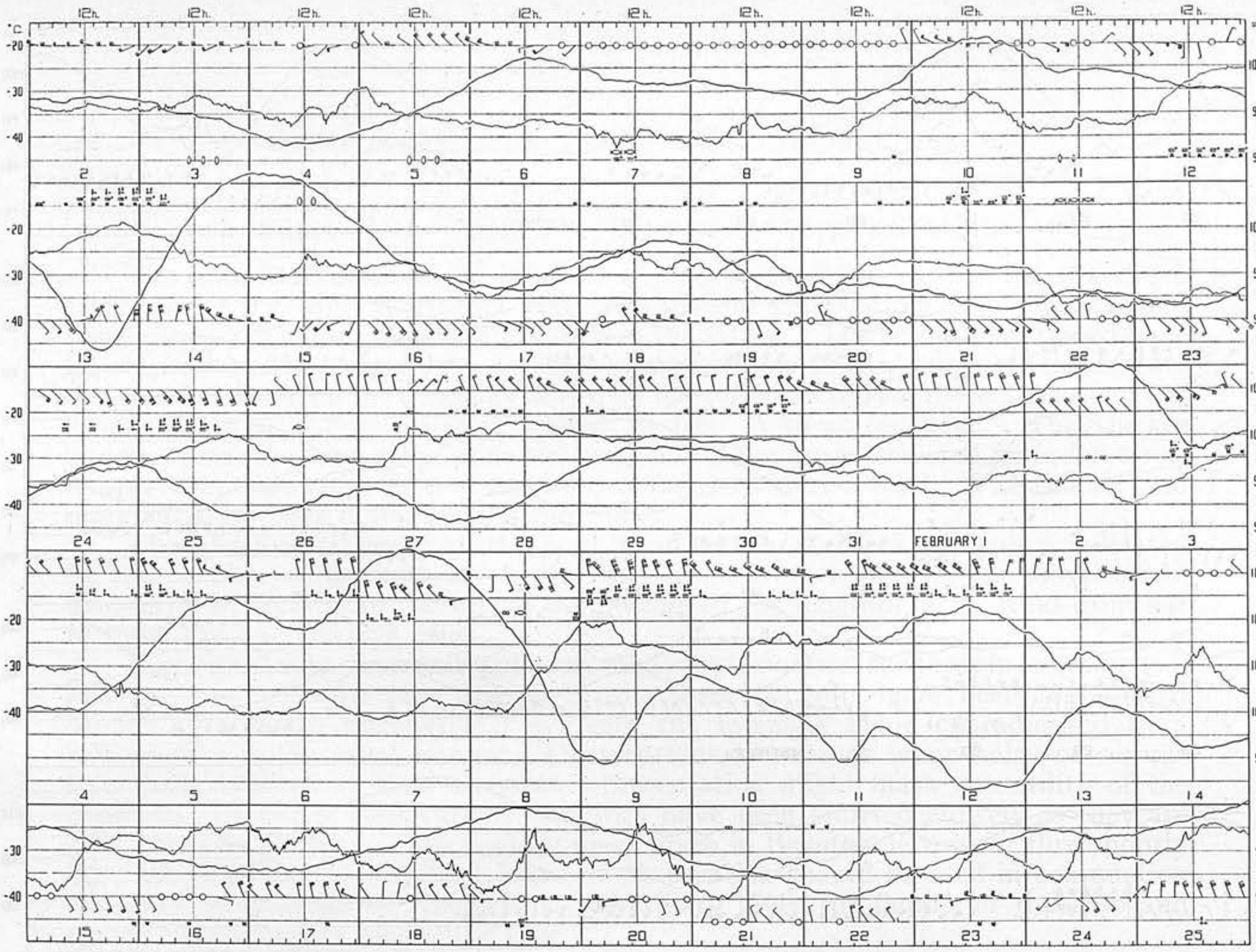


FIG. 38.—January 2 to February 25, 1933.

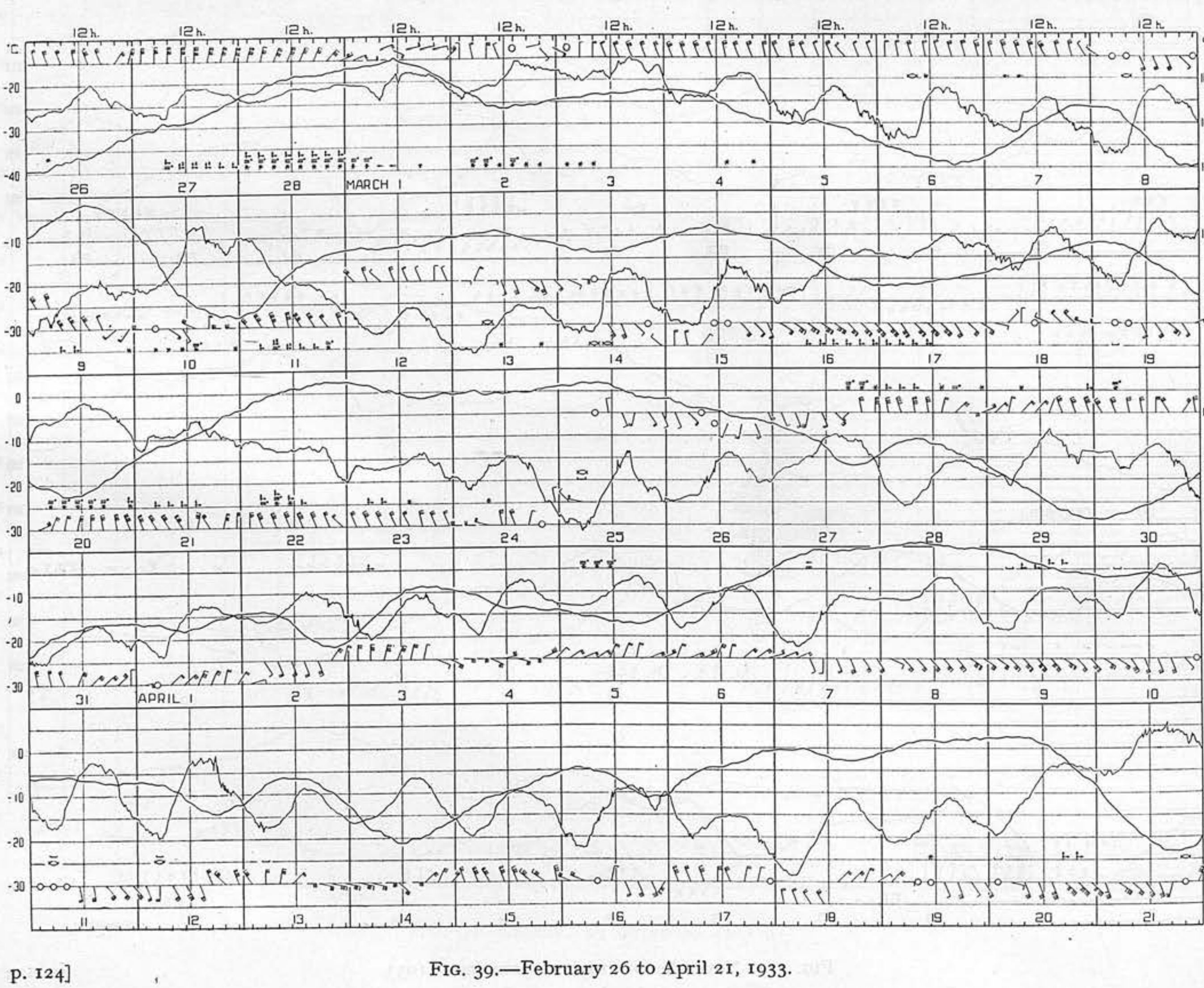


FIG. 39.—February 26 to April 21, 1933.

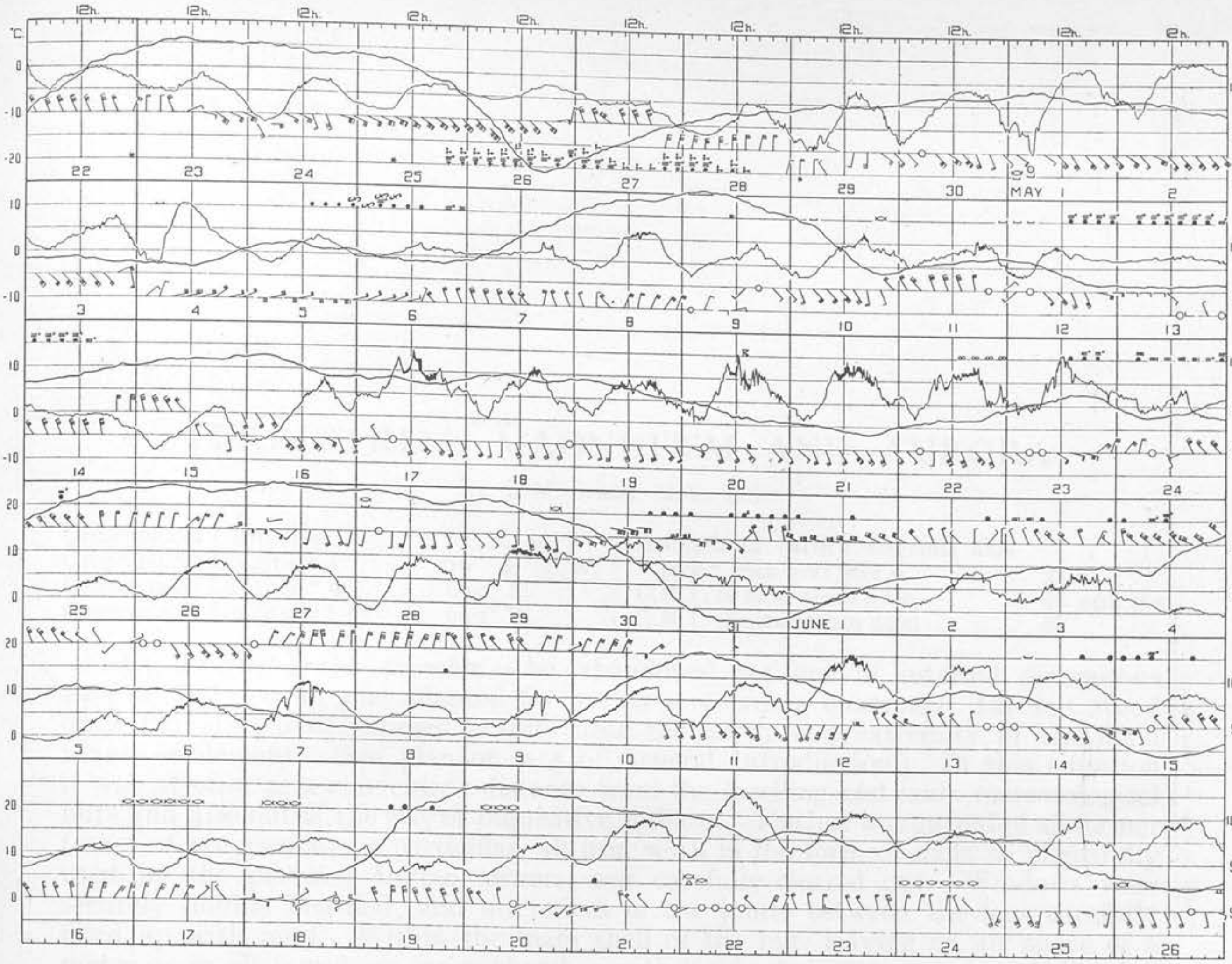


FIG. 40.—April 22 to June 26, 1933.

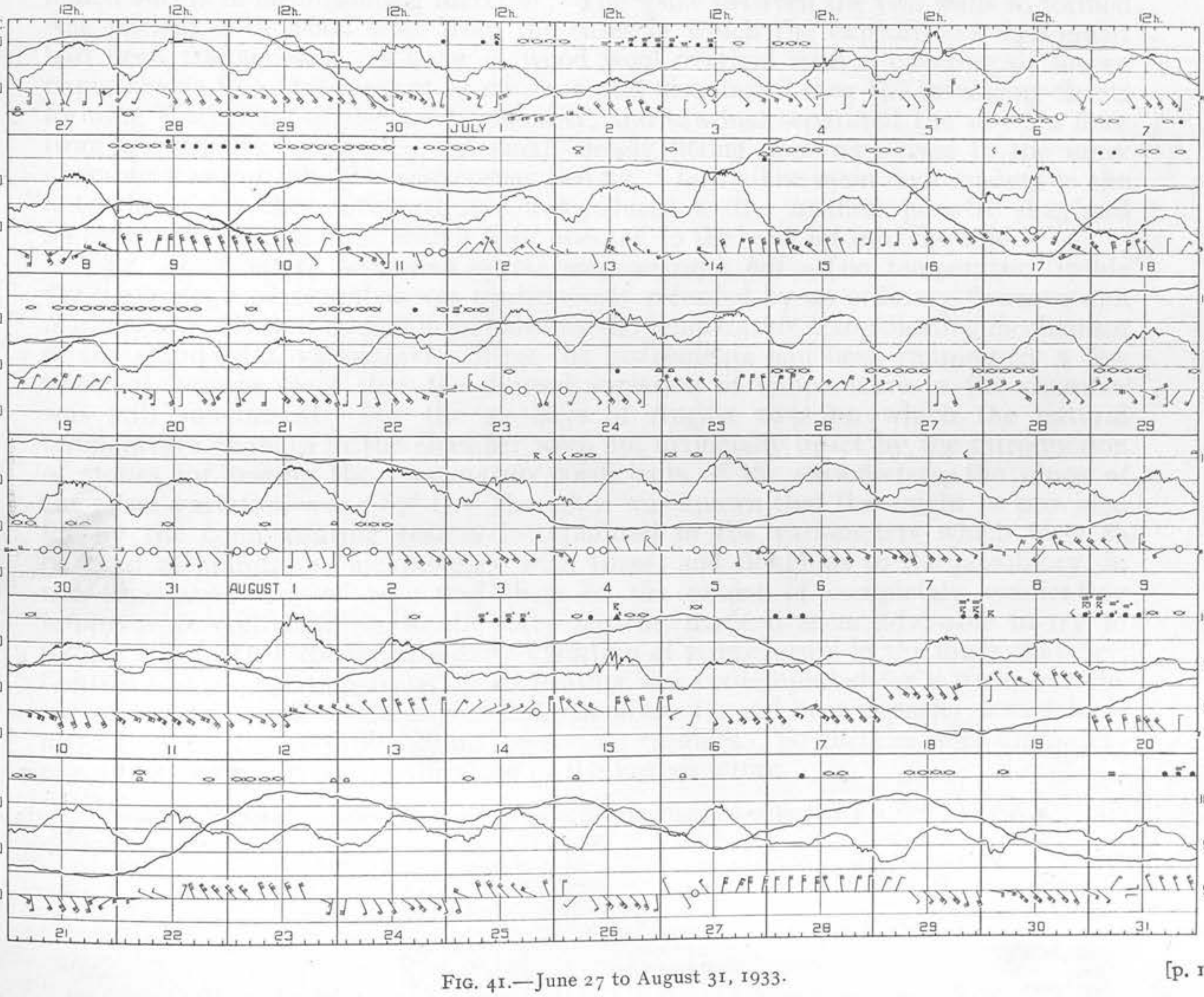


FIG. 41.—June 27 to August 31, 1933.

TERRESTRIAL MAGNETISM AND AURORA

By J. M. Stagg, M.A., B.Sc.

Geographical Latitude ϕ	62° 49′ 46″ N.	Azimuth of earth's magnetic axis pole * from Fort Rae ψ	24·1°
Geographical Longitude λ	116° 4′ 3″ W.	G.M.T. of local mean noon	7h 44m 16s
Geomagnetic Latitude * Φ	69·0° N.	G.M.T. of zonal mean noon	8h
Geomagnetic Longitude * Λ	69·1° W.		

§ 1. *Magnetograph chamber.*—An abandoned log hut of internal dimensions 14·3 m. by 16·9 m. was adapted for use as a recording chamber. The hut stood on a flat stretch of exposed granite near the north-west extremity of the main island settlement. (See plan on p. 5 of General Introduction.) In this situation it was at once at a convenient distance from the dwelling and main meteorological huts and also out of the way of inquisitive Indians. The hut was gutted of all former traces of occupancy; in particular, all iron work in the form of nails, so plentifully used by the previous Indian owners, was carefully cleared out. Windows were securely double boarded, and interstices in the joints between the logs carefully filled up with mud. Within the main shell of the hut, leaving an air space of a metre or so all round, an inner chamber with inside dimensions 10·5 m. by 8·7 m. was constructed of a skeleton of timber to which, on both inside and outside, were nailed sheets of an insulating material. The space between the two walls so formed was packed with wood wool from the cases in which the expedition's equipment had been transported. A layer of wood wool overlaid with a covering of brown paper sheets to a thickness of 25 cm. was also distributed over the insulating sheets forming the ceiling of this inner chamber, and sawdust separated the wooden floor from the granite foundation. A small closely fitting door for access to the inner chamber was cut into the west corner (see fig. 1 (*a*)). The main door leading to the outer hut from the south-east side was reduced to the smallest possible size, and an extension portico built with a door opening to the west let into the side.

§ 2. *Temperature insulation of the magnetograph hut.*—The temperature inside the magnetograph chamber was continuously recorded by an ordinary thermograph made practically non-magnetic and also by the temperature compensating mechanism of the standard Z variometer. After the instruments had been running for a few weeks it became clear that the diurnal variation of temperature in the chamber was still substantial. For the 22 days of August 1932 on which the natural temperature changes in the chamber were not artificially upset by the introduction of stoves for testing the temperature coefficients of the variometers, the range of the mean variation was 1·87° C. Though it was known that this might be provided for by the compensating system incorporated in the variometers which were to be used as standards, inexperience with these, and doubt as to the possibility, in the time available, of adjusting them to the extent of completely eradicating temperature contributions to the force records, made it seem advisable to try to reduce still further the natural daily variation of temperature in the inner chamber. Control of the variation by artificial heating was contemplated for a time, but the use of wood-burning or oil stoves in a chamber of small heat capacity would have introduced other and probably no less serious troubles. So energies were ultimately concentrated on further modification of the hut structure.

* With magnetic axis pole assumed to have geographical co-ordinates $\phi = 78{\cdot}5°$, $\lambda = 69°$ W.

Turf sods were cut into blocks and built up around the outer walls of the hut so as to form an additional wall about a metre thick at the bottom, tapering off towards the roof. Unfortunately, the roof could not be similarly covered owing

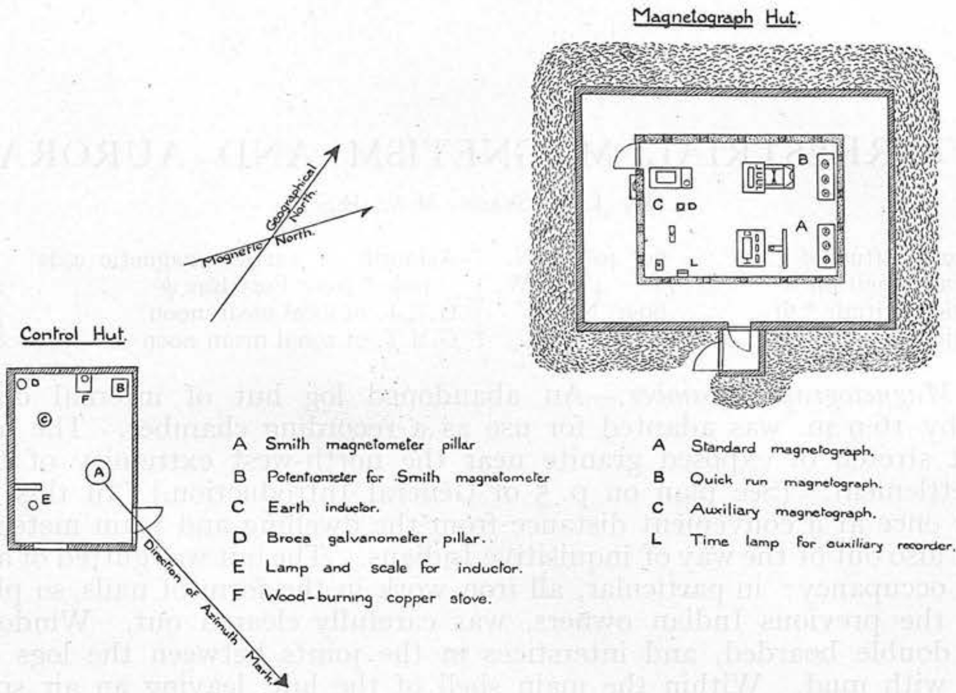


FIG. 1 (*a*).—Plan of relative positions of magnetograph chamber and control hut, with details.

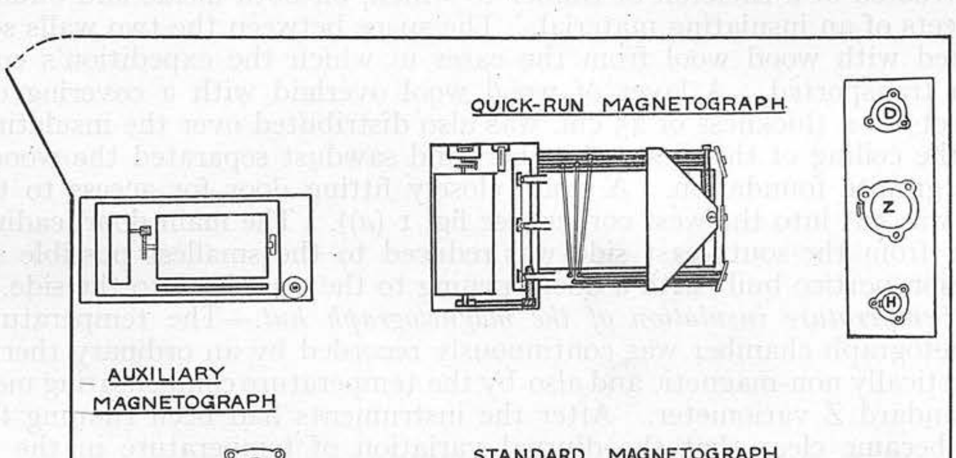


FIG. 1 (*b*).—Plan of arrangements within magnetograph chamber.

to the uncertain strength of the supporting beams, already partly modified to make way for the inner chamber. By the time (early September 1932) this work was in progress, the magnetographs were already functioning, so the risk of collapse of the whole hut structure could not be faced. Plate IV shows the magnetograph hut in July 1932 and as it appeared with its turf walls and snow-covering late in the year. Fig. 1 (*b*) shows the detailed plan of the interior of the hut.

§ 3. *Variation of temperature within the recording chamber.*—The temperature in the magnetograph chamber at every hour throughout the thirteen months of recording was read from the photographic trace made by the compensation element in the Z variometer. These hourly readings were controlled, at least once a day, by readings of a thermometer in the variometer, and the temperature within the H variometer was read almost at the same time. The scale and base line values used in tabulating the records from the Z thermograph are given in Table 1.

TABLE 1.—SCALE AND BASE LINE VALUES OF TEMPERATURE RECORD FROM Z VARIOMETER.

Period.	Scale Value.	Base Line Value.
1932 Aug. 1–22 . . .	$0{\cdot}33_3$° C./1 mm.	− 7·5° C.
1932 Aug. 23–Dec. 31 . .	$0{\cdot}70_5$° C./1 mm.	−28·7° C.
1933 Jan. 1–Aug. 31 . .	$0{\cdot}70_5$° C./1 mm.	−28·4° C.

Table 2 shows the seasonal mean diurnal variations of temperature in the recording chamber. For the four months May to August 1933 the range of the average variation was 0·96° C., which is half that of August 1932. This implies that the insulation supplied by the turf walls roughly halved the daily range. During the winter months, November to February, when the sun was low and the snow-covering heavy, the range of the daily mean variation of temperature was only 0·15° C., and during the four remaining equinoctial months the range was just under 0·5° C., *i.e.* slightly less than midway between the winter and summer values. For the year as a whole, September 1932 to August 1933, the range was 0·51° C.

TABLE 2.—SEASONAL MEAN DIURNAL INEQUALITIES OF TEMPERATURE IN MAGNETOGRAPH CHAMBER.

Hour G.M.T.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	Range
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Winter .	+·01	+·04	+·04	+·05	+·04	+·06	+·06	+·05	+·04	+·03	+·01	−·01	−·02	−·03	−·02	−·02	−·01	−·01	−·01	−·01	−·04	−·06	−·09	−·07	0·15
Equinox	−·05	+·04	+·10	+·18	+·20	+·24	+·24	+·23	+·22	+·18	+·15	+·11	+·02	−·05	−·08	−·11	−·16	−·19	−·21	−·22	−·23	−·25	−·21	−·13	0·49
Summer	+·04	+·18	+·27	+·37	+·43	+·47	+·47	+·46	+·41	+·33	+·23	+·11	+·01	−·11	−·22	−·31	−·39	−·45	−·49	−·49	−·47	−·42	−·32	−·13	0·96
Year .	·00	+·05	+·14	+·20	+·23	+·26	+·26	+·25	+·22	+·18	+·13	+·07	+·00	−·06	−·11	−·15	−·19	−·22	−·24	−·24	−·25	−·24	−·21	−·11	0·51
Aug. 1932	+·29	+·53	+·72	+·87	+·94	+·93	+·89	+·77	+·57	+·43	+·21	+·04	−·25	−·43	−·64	−·80	−·84	−·93	−·94	−·81	−·68	−·52	−·30	−·05	1·87

Although the regular diurnal variation was thus fairly effectively reduced, the daily mean temperatures in the magnetograph chamber (listed in Table 163 of Vol. II and corresponding tables for each month) show that there were large fluctuations from month to month and even from day to day. Discounting August 1932 (which was exceptional in the absence of turf walls and in the frequency of adjustments and the necessity for artificial heating during tests for temperature compensation), the average monthly temperatures (Table 3) in the recording chamber varied from −21·8° C. in February to 14·8° C. in August 1933. On individual days the range was from −24·8° C. on February 7 to 17·7° C. on August 6, 1933. Again, excluding August 1932, the average interdiurnal change of the mean daily temperature throughout the period of functioning of the magnetographs was 0·68° C. As the second last line of Table 3 shows, the change was greatest in June (1·01° C.), when the long hours of sunshine showed up the lack of an adequate roof insulation, and least in January (0·37° C.), when the snow-covering on the roof was most effective. The summary of monthly means of net (algebraic) change of temperature from day to day in the last line of Table 3 serves only to show the general trend of temperature in the recording chamber. The steepest fall was in November and the steepest rise in May: January, February, and July were the months most characterised by fluctuations about the mean temperature rather than by trends in one direction.

TABLE 3.—AVERAGE DAILY TEMPERATURE AND INTERDIURNAL CHANGE IN MAGNETOGRAPH CHAMBER.

	1932.					1933.								Mean.
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Average temperature	18·3	9·0	1·1	−8·5	−14·7	−20·5	−21·8	−16·6	−10·6	−4·6	6·7	12·8	14·8	−2·66
Average interdiurnal change	1·32	0·60	0·52	0·73	0·76	0·37	0·68	0·70	0·61	0·68	1·01	0·79	0·68	0·68
Average algebraic interdiurnal change.	−0·16	−0·11	−0·29	−0·35	−0·24	0·00	−0·03	+0·02	+0·23	+0·35	+0·32	+0·32	+0·03	−0·07

§ 4. *Recording instruments*.—Three complete and independent sets of magnetographs, each recording the three elements of the magnetic field, horizontal force (H), vertical force (Z), and declination (D), were used for continuous registration.

(i) A standard ordinary magnetograph as designed and constructed in Copenhagen for high latitude work (and indeed, in the first instance, specifically for use at the stations taking part in the Second International Polar Year programme). As compared with previous types of magnetographs used in expedition work, the Copenhagen instruments incorporate several novel features:—

(*a*) An optical temperature-compensating mechanism in each of the force variometers. From this, records of temperature within each instrument can be registered along with the changes in the magnetic field.

(*b*) Magnets of relatively small mass (H and D, 25 mg.) and moderate moment in all three variometers, so that they can function together on a table a metre long without risk of undue mutual interference.

(*c*) Suspensions of quartz fibre in the H and D instruments.

(*d*) The vertical force magnet with its mirror and knife-edges forms a single system cut from one piece of artificially seasoned chrome steel. The magnet rests on agate edges of non-linear design and is enclosed in a chamber which can be partially evacuated.

(*e*) The recording mechanism includes three sets of prisms, one set for each variometer, by which auxiliary light-rays from a single lamp can be directed on to the magnet mirrors and focussed back on to the recording drum. This ensures that when the primary ray from any one of the variometers moves off the sheet during disturbance, auxiliary rays come on to continue the registration.

(*f*) By use of a second lamp an auxiliary intermittent record can be made by arranging for illumination of this lamp at any desired interval.

The details of the features of the variometers are adequately described in the *Publikationer fra Det Danske Meteorologiske Institut, Communications Magnétiques*, Nos. 8 and 11. The arrangement of the magnetograph in the chamber is plain from fig. 1 (*b*) and Plate IV.

(ii) A quick-run magnetograph also very recently designed at Copenhagen.

This instrument is now so well distributed among the observatories of the world that it is not necessary to describe its details. It is sufficient here to summarise the chief features. These are: a single light source, a row of 49 small prisms, 3 mirror strips, 3 variometers similar to those used in the ordinary Copenhagen magnetograph, and a special type of recorder which incorporates a moving screen with 3 lenses and protruding light-funnels, the whole screen and its accessories moving bodily forward by the width of each lens once during every revolution of the recording drum. Along with the primary ray from the lamp, 49 rays through the prisms can be focussed, so that after reflection from one of the mirror strips they fall on to the mirror of one variometer and thence are reflected back towards the recording drum. The screen before the drums, together with the light-funnel extending from each lens, ensures that at most 2 (usually only 1) of the 50 light-rays from each variometer mirror reach the recording paper.

The whole design is intended to overcome the difficulty of recording the positions of a system with no fixed zero like a galvanometer, and at the same time to economise consumption of photographic paper. Even with a time scale (180 mm. per hour) twelve times greater than that of the ordinary magnetograph, the quick-run recorder used the same amount of paper as the ordinary one.

The nature of the records from this instrument are not such as to allow hourly values or ranges of large movements to be readily measured. It was primarily designed for accurately timing the incidence of special types of movements, such as sudden commencements, and for determining the fine structure characteristics of changes in the magnetic field.

(iii) An auxiliary ordinary magnetograph. The main purpose in having a third set of magnetographs was to provide for contingencies when the records from the ordinary standard set might be uncertain or lacking, owing to adjustments, clock stoppage, failure of light supply, or any of the many minor accidents that can break continuity in records when reliance is placed on a single instrument. This auxiliary magnetograph was lent by the Admiralty from Greenwich Observatory. The various constituents are described in the volume of *Greenwich Magnetic and Meteorological Observations* for 1915. For reasons to be discussed later (§ 14), only the declination constituent of the Greenwich magnetograph was extensively used, but since the only radical difference between this instrument and other declination variometers was that it used a fine phosphor bronze suspension instead of quartz or silk, no further details are necessary. The arrangement of the 3 magnetographs in the recording chamber is shown in fig. 1 (*b*).

§ 5. *Illumination.*—A 700-watt Delco engine generator supplied current for the illumination. This, together with a storage battery of accumulators, was housed in a log hut 137 m. from the recording chamber. (See plan on p. 5 of Introduction.) Independent sets of leads carried the current from this hut to the ordinary and the auxiliary magnetographs.

§ 6. *Timing.*—A synchronome electric clock in the main observatory hut was the primary source of time control for the three magnetograph sets. The clock was rated daily by time signals from the U.S. Admiralty station at Annapolis. Through the medium of a relay—

(i) The primary traces on the ordinary Copenhagen recorder were interrupted for a time which, during the major portion of the year, lasted 1½ minutes, from 59½m to 61m.

(ii) The auxiliary intermittent lamp on the same recorder was illuminated at each exact 5 minutes and also at a minute before, at the exact hour, and at a minute after each full hour.

(iii) The same intermittent current as in (ii) illuminated the lamp of the quick-run recorder; and

(iv) The same current illuminated a lamp on the south-east wall of the inner chamber (see L of fig. 1), so arranged as to impose a time grid (at each exact 5 minutes, and at 59, 60, and 61 minutes for each hour) across the chart on the auxiliary Greenwich recorder.

Until early November the relay was fitted on the outer wall of the inner chamber of the magnetograph hut. Despite much adjustment, overhaul, and cleaning, increasing cold there so decreased its efficiency in keeping step with the impulses from the main clock that the time-marking circuits were re-arranged to allow the relay to be set up beside the control clock in the observatory hut, where it was under much stricter supervision and in better working conditions. In this position its behaviour improved, but throughout the whole year it required careful attention and frequent adjustment.

§ 7. *Control hut and instruments used.*—On a convenient flat surface of granite rock some 12 metres to the south-west of the magnetograph hut, a hut 3 m. by 2·5 m. was built for the control observations. (See plan on p. 5 of Introduction, fig. 1 (*a*), and also Plate IV.) The arrangement of the main instruments within the hut can be seen from Plate IV. The observations were carried out, for the most part, with a Smith magnetometer (No. L45377 Cambridge Instrument Co.) for horizontal force and declination, and by means of a dip inductor (lent by the Admiralty from Greenwich Observatory) for inclination. In addition to these, the equipment of control instruments comprised a Kew magnetometer, Dover No. 140, and a dip circle. The purpose of these latter instruments was threefold:—

(*a*) To make observations at Old Fort Rae near the site occupied by the 1882–83 expedition;

(*b*) To replace the more modern equipment in case of accidents; and

(*c*) To serve as an occasional control for the results from the untried electromagnetic instruments.

In addition, the Kew magnetometer was an indispensable auxiliary to the Smith magnetometer for determining the angular constant in the float system when the latter instrument was used for observations of declination.

§ 8. *Control observations of H.*—The Smith magnetometer is the only part of the magnetic equipment whose constructional details and principles of use are not generally known. They are given in *Union Géodésique et Géophysique Internationale, Comptes Rendues de l'Assemblée de Stockholm, Section de Magnétisme et Électricité Terrestres*, 1930, pp. 301–309. It is a sufficient indication of the principle on which the magnetometer operates to say that a current, accurately known by balancing through a potentiometer against a Weston cell, is passed round a pair of Helmholtz-Gaugain coils at whose centre is a small magnet-mirror system. The current is predetermined to be such as to produce a flux at the centre of the coil system nearly, but not quite, equal in magnitude and opposite in direction to the earth's field. First the undisturbed position of the magnet is read on an azimuth circle attached to the coils, and again when a balance has been set up by turning the coils in azimuth after the magnet has been deflected. In this balanced position the resultant force on the magnet system is exactly at right angles to the field set up by the known current, so that the value of the earth's horizontal component is given by $H = FC \sec \theta$, where F is a constant for the particular magnetometer, C is the current, and θ is the angle through which the coil system has been swung to allow the magnet to take up its balanced position.

For the Smith magnetometer used as the standard instrument in observing H at Fort Rae, the constant F was determined at Abinger a few weeks before the expedition left England. Provided the coils preserve their shape and size, the constant is invariable except in so far as it requires correction for temperature. The variables for which corrections are necessary are the potentiometer resistances and the E.M.F. of the Weston cell. Two Weston cells were taken and occasionally tested against each other during the year's work. They were also calibrated both before departure from England and after return, and found to remain exactly unchanged.

On arriving at Fort Rae it was found that the potentiometer resistances would not allow a sufficiently small current to be sent through the coils for balancing the earth's field. An additional resistance was inserted into the circuit. On return to England, this resistance was measured at the National Physical Laboratory along with the standard resistances in the potentiometer. Corrections have been applied to the values of H deduced from the Smith magnetometer, using the modified resistance. Account has also been taken of the need for correction to the value of H arising from

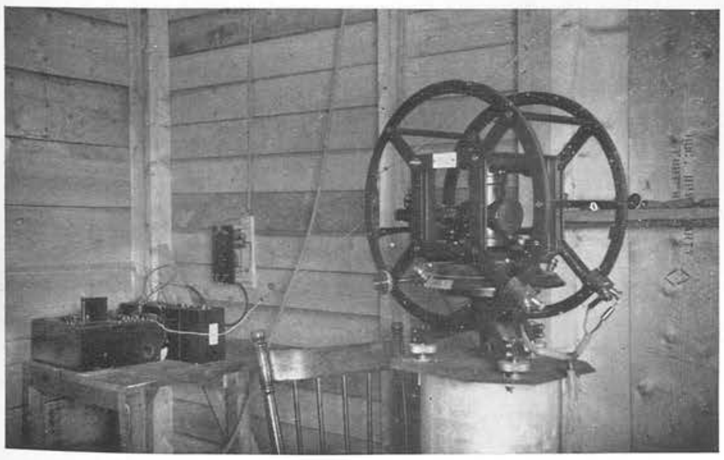
PLATE IV

(*a*) Disused shack which was reconditioned as magnetograph hut.

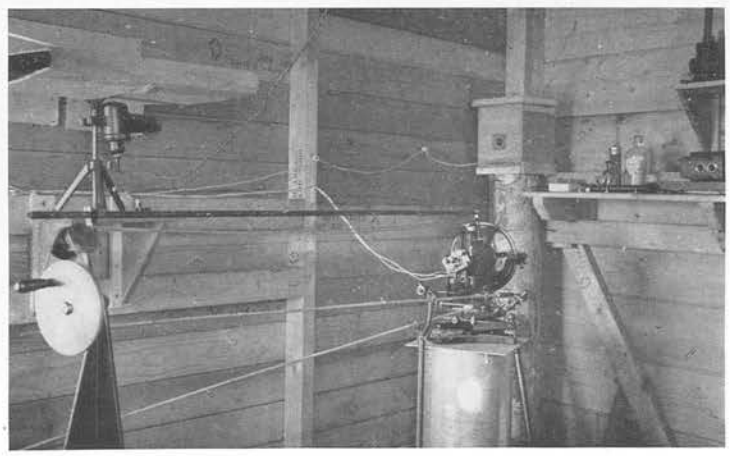
(*b*) Magnetic recording and control huts in winter.

(*c*) Quick-run magnetograph.

(*d*) Standard magnetograph.



(*e*) Smith magnetometer, potentiometer, and battery.



(*f*) Earth inductor with encased galvanometer.

[*To face p.* 132

the comparative proximity of the potentiometer box to the coil system. As used at Fort Rae, the distance between, and relative orientation of, these constituents of the magnetometer were such that the correction is probably of the order of $-0{\cdot}5\,\gamma$ or less; it is therefore neglected.

Few difficulties were encountered in determining H by the Smith magnetometer. The instrument could be used with two types of magnet system: one in which the magnets were attached to a float within a chamber filled with petrol (§ 9), and the other in which the magnet system was suspended by a very fine quartz fibre. Since we wished the magnetometer to serve as a declinometer as well, we used the float system for both H and D throughout.

To ensure that the standard Weston cell incorporated in the potentiometer should not be damaged by extreme cold, the potentiometer was kept in the main meteorological hut, which had to be kept at or above 0° C. to prevent freezing of the water in the anemometer recorder. During the coldest winter months the control hut was warmed by a wood-burning stove, and sufficient time was allowed before starting the observation for all the constituent parts of the magnetometer to approximate to the same temperature.

§ 9. *Control observations of D.*—Since the Smith magnetometer is not primarily designed to measure D, it had been planned to control the declination magnetograph by means of the Kew magnetometer. Because of the need for keeping the observing hut small and owing to the space occupied by the coil and potentiometer of the Smith magnetometer, the dip inductor system and the wood-burning stove, this plan was impracticable. It became necessary to use the Smith magnetometer for observations in D as well as H. Now the magnet system of this instrument consists of a pair of small magnets mounted (in parallel) horizontally below a chamber floating in petrol, the chamber being kept centralised by a jewelled pivot. The float system carries an optically plane cubical mirror fixed rigidly below the magnets; one pair of faces of the mirror cube is arranged to be roughly parallel to the magnets. The movement of the system is observed through a telescope fixed in the coil framework parallel to the plane of the coils. With no current through the coils and the float system freely floating, its position can be read relative to the horizontal circle from any of the vertical faces of the cube. At Fort Rae the west face was invariably used in the application of the magnetometer to D observations.

To determine D absolutely by the Smith magnetometer alone, it would be necessary to have an absolute determination of the angle ϕ between the face of the cube and the magnetic axis of the double magnet system. This is impracticable. The procedure adopted at Fort Rae was to determine ϕ through the medium of the D magnetograms as standardised in an absolute sense by the Kew magnetometer. This was done as follows. Readings of the horizontal circle of the magnetometer were taken (i) when the magnet system was floating freely and the azimuth of the telescope had been adjusted to be normal to the west face of the mirror cube, and (ii) after the magnet and float system was removed and the telescope had been sighted directly on a fixed azimuth mark. If we call these readings R_D and R_m, and if $90°+\lambda$ be the azimuth of the fixed mark, then the value of the declination angle corresponding with R_D would be $(R_D-R_m)+\lambda$ if the west face of the cube were truly parallel to the magnetic axis of the float system. But if the true declination as determined by another magnetometer (in our case by the Kew magnetometer) at the time of R_D is D, then the angle ϕ between the optical and magnetic axes of the system is $D-R_D+R_m-\lambda$. Over a long series of observations made daily for six weeks at Fort Rae the mean values obtained for ϕ and λ were 1° 12·1′ and 13° 10·1′. Hence the equation for true declination deduced by means of the readings R_D and R_m on the Smith magnetometer circle is

$$\text{Declination} = 14°\ 22{\cdot}2' + R_D - R_m.$$

Since the constituent parts of the float system remained unaltered, this relation was used for determining D throughout the year.

§ 10. *Azimuth mark.*—The primary azimuth mark used in observations at the base station was a black line painted on the white gable-end of a hut at E′ 270 m. from the absolute hut. (See plan in Introduction.) Before declination observations were made, the azimuth of the mark was determined in the summer of 1932 by east and west altitude observations on the sun; it was checked in April and May 1933 by the same method, using stars. The result of seven determinations was to give an azimuth of the primary mark at E′ of 103° 10′ 2″ ± 3·8″. Using this determination, a subsidiary mark was set up some 70 m. distant from the absolute hut in the exact line between the centre of the observing pillar in the hut and E′. This allowed the same azimuth to be used when observing declination either by the Kew magnetometer or by the Smith magnetometer; the optical axes of their telescopes being at different heights above the pillar top.

§ 11. *Control observations of inclination.*—The determination of inclination by the dip inductor, though giving two independent values of inclination, really formed one closed cycle of varying positions of the rotating coil and directions of rotation. Indicating the direction to which the graduated circle side of the coil faced by W. or E., whether the adjustable bearing of the coil was above or below the horizontal circle by *up* or *down*, and the direction of rotation of the coil by *c* (clockwise) or *ac* (anti-clockwise), the order of readings in the first half-cycle was W. up *c*, W. up *ac*, W. down *c*, W. down *ac*, E. down *c*, E. down *ac*, E. up *c*, E. up *ac*. This was repeated in the reverse order in the second half-cycle. Readings of level were taken at each stage of the observation, and suitable corrections made to the observed circle reading.

At first, adjustment was also made at each stage for varying declination; but for the greater part of the year the coil was set with its axis in the meridian at the beginning of the observation, and its position in the subsequent stages referred to this initial position. This allowed the observation of inclination to be carried out in almost half the time and detracted little from the resultant value of the inclination. For if the angle between the axis of the coil at any stage in the observation and the true meridian was α, and I′ and I are the observed and true values of the inclination

$$\tan I = \tan I' \cos \alpha,$$

so that, with α small,

$$I - I' = \left(\frac{\alpha^2}{4}\right) \sin 2I.$$

Therefore at Fort Rae with $2I = 165°$, $I - I'$ would be only 4″ if α were 1°.

In the main the dip inductor worked well throughout. At first the Broca galvanometer (used in determining the stage of null current through the coil) was supported on a bracket fixed to the wall of the hut. Vibration of the hut in wind made the light spot very unsteady. This was remedied by introducing an independent pillar for the galvanometer. A more insidious trouble was an unsteadiness in the spot, due to the almost continuous and large changes in the natural magnetic field during the observation and partly to thermo-electric currents set up in the coil galvanometer circuit. The first could not readily be eradicated; the second, aggravated by the smallness of the hut and the need for having the wood-burning stove on the same side as the galvanometer, was very largely reduced by encasing the galvanometer in a box padded with cotton-wool; only a small tunnel was left for the light spot to be thrown from the non-magnetic lamp on to the magnet mirror and reflected back on to the scale.

§ 12. *Procedure in control observations.*—During the three and a half months from the middle of July 1932 till the end of October, observations of H and D were made daily; during the remainder of the Polar Year the observations were made twice a week, but in this period each observation was repeated. The same holds for inclination by means of the dip inductor. In reality, each determination of H was a mean of at least five or six determinations spread over about 25 minutes;

the same is true of D, though the number of observations contributing to each mean was usually eight or ten. The whole observation was generally carried out in this way: (i) Series of observations of D giving one mean D, (ii) series of observations of H, (iii) repeat series of D observations followed by (iv) a repeat series of H observations. These four series seldom occupied more than one and a half hours. A complete double observation of I was then made.

§ 13. *Summarised results of control observations.*—Using the small portable magnetometer for determination of horizontal force and declination, and the dip inductor for inclination, the total number of control observations made at the main base was 289 for H, 251 for D, and 283 for I. In addition to these, a large number (132 of D and 35 of H) were made between July and October 1932, using the Kew unifilar magnetometer. Though these latter were indirectly used in defining the base line values of the main station magnetograms, their primary purpose was to supply a comparison basis when the unifilar magnetometer was used to determine the values of the elements at Old Fort Rae, near the site of the 1882–83 expedition (§§ 27–29).

TABLE 4.—MONTHLY MEAN VALUES OF THE ELEMENTS AS DIRECTLY DETERMINED IN CONTROL OBSERVATIONS.

	1932.					1933.								Winter.	Equinox.	Summer.	Year.
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.				
H (γ)	7750	7752	7749	7744	7725	7737	7747	7736	7752	7743	7765	7742	7743	7738	7747	7749	7745
No. of Obs.	44	38	32	21	12	16	16	18	16	19	18	16	23	65	104	120	289
D37° +	(34·7′)	25·3′	26·2′	25·1′	27·2′	27·2′	26·3′	25·0′	21·5′	23·1′	16·9′	15·2′	17·7′	26·4′	24·5′	18·2′	37° 23·0′
No. of Obs.	38	23	14	15	17	17	17	18	16	18	18	16	24	66	71	114	251
I 82° +	36′ 48″	37′ 15″	37′ 24″	37′ 25″	36′ 43″	36′ 45″	36′ 2″	37′ 56″	36′ 24″	36′ 24″	35′ 48″	37′ 44″	37′ 23″	36′ 45″	37′ 15″	36′ 48″	82° 36′ 56″
No. of Obs.	35	30	39	21	17	19	18	16	12	20	18	16	22	70	101	111	283

Of the observations made with the standard instruments a large number were made in pairs, the pairs being combined in the assignment of base line values. But even in this reduced form, the total number of observations made is too great to publish *in extenso*, so that the former practice (in similar publications) of showing all details of control observations will not be observed. Information is given in §§ 20, 22, and 24 relating to such aspects of the observations as the standard deviations of the quantity (observed–adopted) base line values, regarded in some quarters as a criterion of the reliability of these basic measurements. Table 4 summarises all the control observations, in monthly and seasonal means, of the elements as directly determined. Table 5 gives the average times in each season at which the observations were made, and the correction appropriate to those times necessary to take account of the average diurnal variation on all days of the year. The usual order of observing was such that the mean time of determination of H was about the same as the mean time for D. It is to be noted that, except in a few months when conditions of light and other duties permitted an approximation to routine, the individual times of control observations were widely scattered through the working day. For the primary purpose for which the control observations are made this variability matters little; indeed it has advantages. But when the control observations are used to throw light on the reality of a seasonal change in the mean values of the elements, an approximation to fixed times of observation distributed regularly during each month is a desideratum.

Some aspects of these observed mean values of the elements are considered in detail along with the monthly values based on the magnetogram readings in § 25. Suffice it here to say that, unless the observations have been made rigorously at the same time each day throughout the whole period—and perhaps not even then—they can provide, neither individually nor in monthly groups, any insight to the annual change in the mean values of the elements. The apparently anomalous value in Table 4 for declination in August 1932, for example, should not lead to the conclusion that easterly declination at Fort Rae decreased by $9\frac{1}{2}'$ between August and September of that year, nor that a great proportion of the 38 separate observations contributing to the August mean were faulty: the cause is simply that the majority of the observations were made at a time of day—when the regular diurnal variation of declination was well above normal—different from that chosen in the other months of the year.

TABLE 5.—MEAN TIMES OF CONTROL OBSERVATIONS AND CORRECTIONS FROM ALL-DAY INEQUALITIES APPROPRIATE TO THOSE TIMES.

Season.	H.		D.		Z.	
	Time.	Correction.	Time.	Correction.	Time.	Correction.
		γ		$'$		γ
w	20h 0m–20h 30m	−10	20h 0m–20h 30m	+6·5	20h 15m–20h 45m	+18
e	20h 30m–21h 0m	−23	20h 30m–21h 0m	+9·0	21h 30m–22h 0m	+ 7
s	20h 45m–21h 15m	− 6	20h 45m–21h 15m	+5·9	21h 30m–22h 0m	+ 6

§ 14. *Scale values of declination magnetographs.*—Accurate knowledge of the scale values for each of the three standard traces (H, D, and Z) is the basis of the whole statistical superstructure built up from the traces. As mentioned earlier, it had been the intention to base all such primary tables as hourly values and ranges on the standard Copenhagen magnetograph, but it required little experience with the records from that instrument to see that the D trace was continuous (and therefore straightforwardly measurable) only on the quietest days. With a scale value of 0·95 minute of arc per mm., which, being based on the geometry of the lay-out of the magnetograph constituents, was therefore unalterable without radical change to the lens and prism systems and pillar construction, the subsidiary reflected traces were frequently more in evidence than the primary, and at times during big disturbance could hardly be disentangled from each other. So, while the Copenhagen magnetograph was treated as the standard for tabulation of H and Z, the Greenwich magnetograph was the standard for D. The scale value of this last was 2·09 minutes of arc per mm. as determined by the usual geometrical means and with the usual corrections. The scale values of the two D magnetographs, determined independently, were compared at intervals by measuring ranges of corresponding movements registered on the two records. Except during a period in 1933 from the end of May onwards, for a reason to be discussed at length in connection with the force components, the two D scale values remained reasonably consistent, due allowance being made for the fact that, with two variometers differing so markedly in the inertia of the moving systems and in the means of suspension of their magnets, their reactions to changes in the earth's field depend on the nature of the change. For unless two D variometers are identical, the ratio of their scale values, while remaining substantially constant for a long series of slow perturbations, will show quite a surprising range of values as the perturbations in the field become larger and quicker.

§ 15. *Scale values of horizontal and vertical force magnetographs.*—The scale value of the H variometer, with its small magnet moment and quartz fibre suspension, should have remained sensibly constant throughout the whole period of functioning. With very slight modifications, the same is true of the Z instrument.

The scale value determinations were made with two Helmholtz-Gaugain coils connected in series, one over each of the force variometers, the current being supplied by two big capacity dry cells, and read off from a Weston milliammeter mounted into a box along with a reversing switch and rheostat. The milliammeter was seen to be reading correctly when scale tests were first started, in July 1932, by calibrating it against another milliammeter known to be very good. Though it was known that too many scale tests could as easily be a nuisance as a help in certain contingencies, especially when the scale values were *a priori* expected to remain fairly constant, yet with a new and untried type of variometer, and working under somewhat exceptional circumstances, it was decided to continue at least weekly scale tests. After the instruments were once set up and satisfactorily running, many other jobs claimed attention in the autumn and early winter, so that, except for seeing that no flagrant changes were taking place in scale values (taking into account the great frequency of disturbance at the time of the scale tests), detailed examination of the scale values was delayed till December. It then became evident that apparent changes in scale value were occurring outside the expected limits, and in a manner wholly other than could be attributed to the incidence of disturbance at the time of the tests. On examination it was found that the milliammeter, which had been used for determining the current sent through the standardising coils, had seriously altered its scale value. The cold had apparently affected the spring controlling the movements of the needle. Tests were made to try to get a temperature correction for the milliammeter, but to no purpose. Except for the earliest scale tests when it was known that the milliammeter functioned properly, the tests in the late summer and autumn months up to December had reluctantly to be accepted as valueless. Another means of measuring currents of magnitude suitable for the variometers was available in the form of the potentiometer, which, with its standard cell, was used for the absolute determination of H by the Smith magnetometer. This was successfully tried, and became the routine means of testing from December 1932 till the instruments were dismantled in the early days of September 1933. Scale tests, using the potentiometer, were continued weekly: the field through the variometers (H and Z simultaneously) was increased to the extent of 318 γ in the direction first of increasing force, then decreasing. This was repeated. Though part of the uncertainty in measuring the resulting deflections as recorded on the magnetograms arises from the magnets of the Copenhagen magnetograph being practically undamped, a large contribution also comes from the almost continuous unsteadiness of the field. During the whole year the average hourly range in H was 92 γ and in Z 76 γ. In such circumstances, if the time required for the magnet to resume a steady position after deflection is more than a very few minutes, the field changes naturally to such an extent that the undisturbed line from which the deflection produced by the superimposed force is to be measured becomes uncertain. The imposed field must be changed very gradually to prevent oscillations. Latterly, instead of waiting for the magnet to settle, the mean positions of swing at the various deflected and undeflected positions of the magnet were measured for estimating the extent of the deflection. This allowed the duration of the test to be reduced to a minimum, so that the error introduced by the change in the natural field during the test was kept low.

From December 1932 to the end of May 1933, through a range of temperature in the recording chamber of 26° C., the scale values of both the H and the Z variometers, as determined by about 40 scale tests, remained practically constant. For H from 34 tests the value in γ per mm. was $13{\cdot}75 \pm 0{\cdot}045$, and for Z from 39 tests, $11{\cdot}25 \pm 0{\cdot}052$. Five tests in H had to be discounted in determining these means, because disturbance at the time of the test made the H deflections very much more unreliable than those in Z.

§ 16. *Effect on scale values of great seasonal range of humidity within the recording chamber.*—These results, along with direct correlations carried out between the individual scale value determinations and the corresponding temperatures within the variometers at the time of the test, made it clear that there was practically no temperature coefficient in the scale values of the force instruments. This was very important. For, since the magnetograph constituents had not been altered in any respect affecting the scale value since they were installed in July 1932, and since the best of the early scale tests confirmed that the variometers had begun with scale values very near those which had remained constant over such a large range of temperature, it was completely safe to assume that the scale values had remained constant from August 1932 to May 1933. Indeed, there seemed every justification for extrapolating through to the end of the Polar Year and so saving the time of weekly scale tests. Fortunately, this was not done. For, early in June, changes in the scale values, both of the H and the Z variometers, again appeared in a completely unaccountable way. From the steady value of 13·75 γ per mm. the H scale value rose progressively to 13·94 γ per mm., and at the same time the Z value rose from 11·25 γ to 11·34 γ per mm. Not expecting such changes after the long period of steadiness, the anomalous changes were not noted immediately, otherwise the true cause might have been detected and much subsequent labour saved. Leakage of current from the testing gear would have simulated the effect, a leakage which in some way varied during the summer season. Every constituent was overhauled and tested, but without showing up any defect. All other likely factors were investigated, but without result. The mystery remained unsolved at Fort Rae. In the face of the constancy of the scale values through such a range of temperatures as 26° C. and their agreement with the values obtained in July 1932, the acceptance of a uniform value for each variometer throughout the period seemed called for, and was indeed used. Base line values for the whole superstructure of hourly values were assigned on the strength of constant scale values.

During a subsequent examination of the records, blurring of the traces, due to deposition of moisture on the lens system diffusing the light before incidence on the sheet, recalled that from the end of May till the time of leaving Fort Rae conditions in the inner chamber of the recording hut differed from those obtaining at any other time of the Polar Year in the high moisture content of the chamber. As outside temperature had risen, frost in the walls and floors and sawdust under the floor boards melted, to make everything within the chamber wet: even the daily charts when taken off each afternoon were perceptibly damp. Now the scale tests had always been made in the afternoon just before changing, when the charts were most damp. Hence, though the deflection on the chart in this condition was the same as before, the measured deflection produced by the same field appeared less after development and drying than when the tests were made under the extremely dry conditions before the thaw. This effect was seen to account for all aspects of the anomaly: (i) The changes in scale values of the force components were proportional to the deflections, *i.e.* to the scale values, since the same field was sent through both testing coils. (ii) It accounted for the change appearing when it did in early June, reaching a maximum in the latter part of July, and beginning to fall again as the chamber was dried artificially towards the time of our evacuation. And (iii) it accounted for there being no corresponding phenomenon in the summer months of 1932, for then we had just built the chamber after the hut had stood open and derelict for many months so that the interior was quite dry.

Fortunately, the detection of the anomaly had incited us to more frequent tests during July and August 1933, so new scale values could be assigned with strict relation to the results of the tests. From June to September 1932 the scale values used in the reduction of the H records increased from 13·75 to 13·94 γ per mm. with a standard deviation of the quantity (observed–accepted) value of $\pm$ 0·074. These figures were derived from 37 determinations. In Z the corresponding range in scale value is 11·25 to 11·34 γ per mm. with a standard deviation of $\pm$ 0·043 from 40 determinations.

Over the period December to early September, during which scale values were determined by the potentiometer, the standard deviation from 71 determinations was $\pm$ 0·006, or 0·4% of the H scale value, and $\pm$ 0·048 from 79 determinations in Z, also 0·4% of the scale value.

It should be mentioned that it has subsequently been verified that spurious scale values up to 3% in error can readily be produced artificially on photographic records which have been damped at the line of the scale test and measured in the dry state after development. In comparison with this, the maximum error to be accounted for in the Fort Rae records was only between 1% and 2%.

A similar proportional change would take place in the case of the D trace registered on the same chart as the standard H and Z on the la Cour magnetograph, but this trace was not used for the basic tabulations. The recording drum of the Greenwich magnetograph worked in a wooden box which, except for a pendulum hole, was fairly tight. So that the chart which has been used for the standard D tabulation was never subjected to the same saturated atmosphere as the Copenhagen chart, working as it did on a drum in a light-tight but loosely fitting metal case. It has not therefore been thought necessary to make any modification in the constant scale value used for the Greenwich (*i.e.* standard) D record.

The detailed scale values for the standard instrument records, which are used for the tabulation of all subsequent data, are summarised in Table 6.

§ 17. *Temperature coefficients of H and Z variometers.*—With the scale values satisfactorily determined, the assignment of base line values rests entirely with the control observations. If these are sufficiently frequent, mutually consistent, and carried out with appropriately good instruments, the assignment of base line values theoretically becomes one of plotting the observed values and, with due allowance for the effects of disturbance, drawing a smooth line from which the base line values to be used are read off.

In practice the process is hardly ever quite so simple. Except at those stations where there is ample opportunity of adjusting the temperature compensation mechanism in the force variometers to such a degree of precision that the records of force components may be considered completely free of temperature effects, regard must always be had both to the long-period temperature changes and to those of shorter period within each day. At such a station as Fort Rae, where the time and opportunity for complete eradication of temperature effects was lacking, even assuming it had been possible, the best that could be done was to ensure that the necessary temperature corrections would be as small as possible consistent with a minimum of handling of the variometers, after which reliance had to be placed on the adequacy of the insulation of the recording chamber as a whole for reducing to a satisfactory minimum the most insidious of the temperature contributions—that of the diurnal variation.

As regards the latter aspect of the question, details have already been given (§ 2) about the procedure adopted for thermally insulating the recording chamber in which the magnetographs functioned. The values of the range of the mean diurnal variation of temperature in Table 2 show that the temperature contribution to the records of magnetic force within the average day would be small even with comparatively large temperature coefficients of the variometers. During the greater part of the year, however, the coefficients of both the H and the Z variometers were small; for H, except for a period of less than two months, from 1932 August 23 to October 15, the coefficient was less than 3 γ/1° C. (actually under 2 γ for the first 23 days of August 1932), and probably not exceeding 2·7 γ/1° C. for the $10\frac{1}{2}$ months from October 15 onwards. From 1932 August 23 until the end, the corresponding Z coefficient was about 1 γ/1° C. Using these facts along with the mean daily variations of temperature within the recording chamber (Table 2), it is clear that false contributions to the true daily change of magnetic force, arising from incomplete temperature compensation, are not likely to exceed 1 γ in any part of the whole term of functioning of the variometers except between 1932 August 23 and October 15 in H and for the first 23 days of August 1932 in Z.

§ 18. *Methods of determining the temperature coefficient of variometers.*—The circumstances underlying these exceptional periods require further comment. When the H variometer was installed, the temperature compensation mechanism was adjusted to what was thought to be the correct amount. Some early tests

TABLE 6.—SCALE VALUES USED IN REDUCTION OF RECORDS.

D 2·09 minutes of arc/mm. throughout.
H 13·75 γ/mm. to 1933 June 13.
Z 11·25 γ/mm. to 1933 June 24.

Date.	H (γ/mm.).			Z (γ/mm.).		
	June.	July.	August.	June.	July.	August.
1	13·75	13·85	13·94	11·25	11·28	11·34
2	13·75	13·86	13·94	11·25	11·28	11·34
3	13·75	13·86	13·94	11·25	11·29	11·34
4	13·75	13·86	13·94	11·25	11·29	11·34
5	13·75	13·87	13·94	11·25	11·30	11·34
6	13·75	13·87	13·93	11·25	11·31	11·34
7	13·75	13·88	13·93	11·25	11·31	11·33
8	13·75	13·88	13·92	11·25	11·31	11·33
9	13·75	13·89	13·92	11·25	11·32	11·32
10	13·75	13·89	13·92	11·25	11·32	11·32
11	13·75	13·90	13·91	11·25	11·32	11·32
12	13·75	13·90	13·91	11·25	11·32	11·31
13	13·75	13·91	13·90	11·25	11·33	11·31
14	13·76	13·92	13·90	11·25	11·33	11·31
15	13·76	13·92	13·90	11·25	11·33	11·30
16	13·76	13·92	13·89	11·25	11·34	11·30
17	13·76	13·92	13·88	11·25	11·34	11·29
18	13·77	13·92	13·87	11·25	11·34	11·28
19	13·77	13·93	13·86	11·25	11·34	11·28
20	13·78	13·93	13·85	11·25	11·34	11·28
21	13·78	13·94	13·85	11·25	11·34	11·27
22	13·79	13·94	13·84	11·25	11·34	11·26
23	13·79	13·94	13·83	11·25	11·34	11·25
24	13·80	13·94	13·82	11·25	11·34	11·25
25	13·81	13·94	13·82	11·26	11·34	11·24
26	13·81	13·94	13·81	11·26	11·34	11·24
27	13·82	13·94	13·80	11·26	11·34	11·23
28	13·83	13·94	13·79	11·26	11·34	11·23
29	13·84	13·94	13·78	11·27	11·34	11·22
30	13·84	13·94	13·78	11·27	11·34	11·21
31	..	13·94	13·77	..	11·34	11·21

confirmed the adequacy of the compensation. But further tests on August 20–23, made by artificially heating the recording chamber for short periods, appeared to show that the compensation in the H variometer was unsatisfactory. Here it is probably necessary to describe briefly the methods adopted for determining the temperature coefficient. On the assumption that, as at Fort Rae, all the recorders are in the one chamber and therefore substantially in the same conditions of temperature, by far the best and safest method is to base the determination on changes of the base line value (from which pure mechanical drift has been eliminated) over long periods in which the temperature of the recording chamber has slowly altered. But during such a relatively short period as a year, when continuity and certainty of records are the primary considerations, such a procedure cannot be adopted. Recourse must be had to artificial heating of the chamber for short periods—short because of three reasons:—

(i) To reduce the period in which real and regular changes of the magnetic field are contributing to the record. For there is always the uncertainty that, say, a period of quickly falling magnetic force may offset what ought to be an apparent rise, owing to a temperature effect.

(ii) To reduce the period when irregular real magnetic changes make an estimate of the temperature effect unmeasurable.

(iii) To reduce the subsequent uncertainty in the tabulation of hourly values for the period during which the test is in progress.

Now the necessity for keeping the time of the test as short as possible itself introduces serious uncertainties, the chief of these being the lack of guarantee that the temperature, as read from a thermometer inserted into the variometer case, represents the true temperature of the magnet system. This is especially true of variometers of the type of the Copenhagen Z, where the magnet is enclosed in a thick-walled partially evacuated chamber, while the thermometer rests in, and in contact with, a tube to which there is access of the room air. In retrospect, and on the evidence of the information about the true temperature coefficients derived from an examination of the base line values over the year's working, the results of several series of tests at Fort Rae have shown that a test by artificial heating of a low thermal capacity chamber is unsatisfactory, unless the heating can be prolonged over several hours and can be repeated without fear of loss of record on a number of days chosen for their magnetically quiet conditions, and at times of the day when the regular diurnal changes of magnetic force are small and known. It should be added that the use of an auxiliary magnetograph, housed in a separate chamber whose temperature can be kept constant, eases the problem considerably, but at the usual magnetic observatory, and, *a fortiori*, at a temporary station, such a luxury is not usually available.

Difficulties such as those outlined above were present *in excelsis* at Fort Rae, with the added one of uncertainty of scale value at the time as described in § 15. Incidence of disturbance and false estimate of the temperature attained during tests in August 1932 led to the H temperature compensator being readjusted on August 23, when, as has subsequently been seen, it was already satisfactorily adequate (less than $2\,\gamma/1^\circ$ C.). For two days after the adjustment the compensator was ineffective owing to the constituent prism fouling on a neighbouring prism ; from the afternoon of August 25 to the afternoon of the 26th, when it was again adjusted, the coefficient was about $5\,\gamma/1^\circ$ C., and then from August 26 to October 15 it remained at $6{\cdot}5\,\gamma/1^\circ$ C., when, after a further series of tests, it was changed to what became its value throughout the rest of the Polar Year, about $2{\cdot}7\,\gamma/1^\circ$ C.

From the time of setting up the Z variometer in July 1932 the compensation system was left unaltered at what eventually was estimated to be producing a coefficient of about $18\,\gamma/1^\circ$ C. till August 22, when it was reduced to something just over $1\,\gamma/1^\circ$ C., and on the following day to its final value of probably just under $1\,\gamma/1^\circ$ C. The net result, as explained earlier, is that so far as concerns the diurnal variation of temperature and its effect in contributing a spurious additional variation to the recorded magnetic forces, we need consider only the periods in which the temperature coefficients of the H and the Z variometers exceeded $3\,\gamma/1^\circ$ C. At or below this value the contribution can be neglected, since its magnitude is of the order of $1\,\gamma$.

§ 19. *Assignment of H base line values during periods of large temperature coefficient of force variometers.*—Apart from the three days 1932 August 23 to 25, when the H records were given special treatment, the period August 26 to October 15 is the only one in H requiring attention, and will now be discussed. From the tabulated hourly ordinates representing the temperature of the compensator in the Z variometer and the simultaneous pairs of temperature readings of the thermometers in the H and Z variometers (three per day during the period), the temperature within the H variometer could be accurately estimated, both as regards hour-to-hour variations and daily means. Then, corresponding with each control observation of H, the temperature in the variometer was tabulated, and, using the temperature coefficient for the variometer confirmed by various tests, a relation was found allowing all the base line values in this period to be reduced to 0° C. The value of this 0° C. base line value was $7450\,\gamma$, *i.e.* this is the steady value (due allowance being made for mechanical drift) which the base line value would have had throughout the time if the temperature of the variometer had been maintained at 0° C. From this, using a temperature coefficient of $6{\cdot}5\,\gamma/1°$ C., a base line value was computed corresponding with the mean temperature in the variometer each day. To this set of mean daily base line values there remained to be added the variations within each day due to the diurnal variation of temperature within the chamber. For, though the regular seasonal mean diurnal variations of Table 2 are small, yet on individual days the change from hour to hour was substantial, especially in August and early September, before the turf was piled up around the outer walls of the hut and before the winter snow-covering had formed. In effect, then, the procedure adopted was to superimpose on the mean H base line value for each day during the doubtful period a correction for each hour of the day, the magnitude of this correction being determined by the hourly mean temperatures in the H variometer.

§ 20. *H base line values in general.*—This special treatment provided for the period of less than two months, 1932 August 26 to October 15, when the temperature coefficient of the H variometer was $6{\cdot}5\,\gamma/1°$ C. During all the rest of the Polar Year the variometer continued without adjustment, with a coefficient which probably did not exceed $2{\cdot}7\,\gamma/1°$ C., and when the mean regular diurnal change of temperature in the recording chamber seldom was more than 1° C. Hence for the whole of the remainder of the time after October 15 it was sufficient to plot the base line values derived from the Smith magnetometer observations and draw a smoothed curve through them.

As already explained (§ 12), the absolute observations were made daily till the beginning of November, then in pairs twice weekly from November 1932 to the end of August 1933. Treating the mean base line value derived from each of the pairs of observations in the main period as single values, the standard deviation of the quantity Δ = (observed–adopted) base line value for all the 174 absolute observations of H from early August 1932 onwards was $\pm\,4{\cdot}8\,\gamma$. It is true that this measure of the closeness of fit of the adopted to the observed base line values can in certain contingencies have little significance. By making the line from which the adopted base line values are derived pass through the plots of observed values, the standard deviation can be reduced to zero, even though the observed values are themselves inaccurate. But with such an instrument as the Copenhagen H variometer, whose stability of behaviour can be relied on after a short experience with it, and using control observations made by a direct electromagnetic method in which such factors as friction in bearings, unknown changes in fundamentals, and anomalous behaviour in subsidiary constituents of the system can be discounted (*cf.* the dip inductor, § 22), the standard deviation of Δ becomes simply a measure of the effects of disturbance and of small observational and curve-reading uncertainties involved in the determination of H base line values.

The H base line values accepted for the tabulations are given in Table 7. For the reasons discussed in detail above, the values entered for August 25 to October 15 are mean values for each day; during this period values were separately allocated for each hour of the day.

§ 21. *Base line values for Z during period of large temperature coefficient of variometer.*—The allocation of base line values for the Z variometer was at once simpler and more troublesome than for H. The period of uncertainty of the temperature coefficient for the instrument was much shorter (only 23 days of August 1932) than

TABLE 7.—ADOPTED BASE LINE VALUES: H.

Date.	1932.					1933.							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
1	7485	7401	7431	7355	7362	7366	7382	7378	7364	7351	7312	7282	7274
2	7485	7405	7435	7355	7363	7367	7384	7376	7363	7350	7312	7283	7274
3	7485*	7413	7436	7356	7365	7368	7385	7374	7363	7348	7312	7283	7273
4	7482	7409	7434	7356	7367	7370	7386	7372	7363	7346	7312	7283	7273
5	7482*	7403	7426	7356	7368	7372	7387	7371	7362	7343	7312	7283	7273
6	7417	7392	7440	7356	7368	7373	7387	7370	7362	7342	7312	7282	7272
7	7417	7396	7448	7356	7368	7375	7387	7370	7362	7340	7312	7282	7272
8	7416	7397	7457	7356	7368	7376	7386	7370	7362	7339	7311	7282	7272
9	7416	7394	7461	7357	7367	7378	7385	7370	7362	7339	7310	7282	7271
10	7415	7395	7460	7357	7365	7379	7384	7371	7361	7338	7309	7282	7271
11	7414	7392	7460	7358	7362	7379	7381	7372	7361	7338	7306	7282	7271
12	7413	7402	7460	7359	7359	7380	7379	7372	7361	7338	7303	7282	7271
13	7411	7412	7469	7360	7359	7380	7378	7373	7361	7337	7300	7282	7271
14	7414	7414	7470	7361	7359	7380	7377	7373	7361	7336	7297	7282	7271
15	7414	7414	7469*	7362	7360	7380	7377	7373	7361	7335	7296	7281	7271
16	7416	7413	7353	7362	7361	7379	7377	7372	7361	7333	7296	7281	7271
17	7415	7417	7353	7362	7362	7379	7378	7370	7362	7330	7295	7281	7272
18	7417	7416	7353	7362	7363	7378	7378	7368	7362	7326	7295	7280	7272
19	7418	7415	7353	7362	7363	7378	7379	7366	7361	7324	7295	7280	7273
20	7416	7417	7354	7362	7364	7378	7379	7364	7360	7323	7295	7280	7273
21	7413	7416	7354	7363	7364	7378	7380	7362	7358	7322	7295	7280	7274
22	7412	7413	7354	7363	7364	7378	7380	7361	7355	7321	7292	7280	7274
23	7411*	7411	7354	7363	7364	7378	7380	7361	7354	7319	7289	7280	7275
24	7392	7415	7354	7363	7364	7378	7380	7361	7353	7317	7286	7280	7276
25	7392*	7426	7354	7363	7363	7378	7380	7362	7353	7315	7284	7279	7276
26	7377	7431	7355	7362	7363	7378	7380	7362	7352	7313	7283	7279	7277
27	7377*	7428	7355	7361	7364	7377	7380	7363	7352	7313	7283	7278	7278
28	7357	7427	7355	7361	7365	7377	7379	7364	7352	7312	7283	7277	7279
29	7385	7424	7355	7361	7366	7378	..	7364	7352	7312	7282	7276	7280
30	7396	7424	7355	7361	7366	7379	..	7364	7351	7312	7282	7275	7280
31	7403	..	7355	..	7366	7380	..	7364	..	7312	..	7275	7281

* Aug. 3. 7482 from 3 hr. Aug. 23. 7392 from 3 hr. Aug. 27. 7332 from 3 hr.
„ 5. 7418 „ 4 hr. „ 25. 7377 „ 3 hr. Oct. 15. 7353 at 24 hr.

for H, but the means of determining it were much more open to doubt. This was due to the following causes:—

(i) The indirect method of deriving the base values.

(ii) The shorter period available for critical examination.

(iii) The continuous and large scale magnetic disturbance prevailing throughout the time.

(iv) The number of artificial discontinuities in the record.

(v) The complete uncertainty of the mechanical drift that might be taking place in the record, either owing to the variometer magnet accommodating itself to its seating, or unknown distortion in the supporting pillar arrangements at that early date; and

(vi) The uncertainty of knowing the true temperature of the magnet system in the variometer during short duration tests by artificial heating.

After trial of many methods of obtaining an estimate of the temperature coefficient of the Z variometer from tests made during the first 23 days of August, each method being designed to reduce the uncertainty from one or more of the sources of doubt mentioned above, a value of 18 $\gamma/1°$ C. was accepted. The coefficients deduced from the individual estimates were 13·7, 14·8, and 16·5 $\gamma/1°$ C. (obtained by considering ordinates at selected quiet periods each day along with the corresponding temperatures in the variometer), and 20 $\gamma/1°$ C. deduced by measuring the apparent change in ordinate produced by artificial heating of the variometer.

With the lingering uncertainty in the temperature coefficient as finally accepted, and in view of the considerable scatter in the observed base line values for this magnetically disturbed period, it was thought inexpedient to follow the procedure adopted for H in assigning base line values to Z during the first three weeks of August 1932. The data were not sufficiently well founded to warrant making an estimate of the 0° C. base line value and building up from that. Instead, a mean was found for all the observed base line values for the period, and also for the mean temperature in the variometer at the time of the observations. Departures of each daily mean temperature in the variometer from this over-all mean were found, and so, using the accepted temperature coefficient of 18 $\gamma/1°$ C., corrections to the over-all mean base line value were found appropriate to each day. Then, using the hourly departures of temperature in the variometer from each separate day's mean, corrections to the daily mean base line value, appropriate to each hour, were computed on the same 18 $\gamma/1°$ C. basis. Thus, in essence, the method was one of determining hourly values of base line for the Z record during the first 23 days of August 1932, but compared with the method adopted for H, it referred the assigned base line values more directly to the observed values.

§ 22. *Z base line values in general.*—For the rest of the year, with a temperature coefficient of the Z variometer not exceeding 2 $\gamma/1°$ C., the straightforward process used with the H base line values was adopted. They were plotted, and a smooth run drawn from which the values for each day were assigned. As for the H base lines, a value of $\sqrt{\{\Delta^2/(n-1)\}}$ was computed, where Δ is the difference between the observed and the assigned base line. For the twelve months from 1932 September 1 the standard deviation is $\pm$ 30·4 γ. If the troublesome first August is included, this figure becomes $\pm$ 31·5 γ.

That the value of the standard deviation for Z base line values is so much higher than for H is to be expected from the indirect mode of their derivation through I and H. With the elements of the magnetic field as at Fort Rae, 1′ in I entailed a change of 137 γ in Z or 18 γ in H on the average day. With the comparatively low sensitivity of the recording instruments (13·75 γ/mm. in H and 11·25 γ/mm. in Z) and consequent possibility of error in reading the mean ordinates at the time of the observation, with the great prevalence of disturbances throughout the year and with the difficulties of manipulating the dip inductor described in § 11, it is probably not surprising that the standard deviation of the Z base line values should be about 6½ times that for H. As has been urged before, the real need in such work is for an instrument of a convenient and dependable type, capable of reading vertical force directly.

The accepted base line values for Z are given in Table 8, those for the first 23 days of August being mean values for each day. During this period separate hourly base line values were assigned on the basis of the temperatures within the Z variometer.

§ 23. *Use of auxiliary H and Z magnetographs.*—In all the discussion about base line values up to this stage we have been concerned with the standard Copenhagen variometers for H and Z alone. It might have been surmised that the auxiliary magnetograph which incorporated both a horizontal force variometer and a Watson quartz fibre vertical force variometer, as well as a declination instrument, might have been used to decide some features of doubt in the running of the standard set. On

TABLE 8.—ADOPTED BASE LINE VALUES: Z.

59,000 γ + Tabulated Values.

Date.	1932.					1933.							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
1	553	520	537	563	587	615	644	663	673	688	732	779	828
2	528	519	538	564	588	616	645	663	674	689	734	781	830
3	566	519	539	565	589	617	646	662	675	689	736	783	831
4	532	519	540	566	590	618	647	662	676	690	738	784	833
5	524*	519	542	567	591	618	648	662	677	690	740	785	835
6	543*	519	543	567	592	620	648	662	678	691	742	786	836
7	427	519	544	567	593	621	648	662	679	691	744	788	838
8	416	519	545	567	594	622	649	662	680	692	745	792	839
9	400	519	545	567	595	624	651	662	680	693	747	794	840
10	419	520	546	568	596	625	653	661	681	694	749	795	841
11	414	522	546	569	597	626	655	661	681	695	750	796	842
12	414	523	547	570	598	627	657	661	682	697	752	797	843
13	405	524	548	571	599	628	658	661	682	699	753	800	846
14	448	525	549	572	600	629	659	661	683	701	754	802	847
15	475	525	549	573	601	629	661	661	683	703	755	804	847
16	452	525	551	574	602	630	662	661	684	705	756	805	848
17	429	526	554	575	603	631	663	661	684	706	757	806	849
18	420	527	552	575	604	632	663	661	685	708	759	807	851
19	486	528	553	576	605	633	663	661	685	709	761	807	852
20	474	528	554	577	605	634	663	662	685	711	763	808	853
21	448	529	555	578	605	635	663	663	685	713	765	810	854
22	436	530	556	579	606	636	663	664	685	714	767	812	856
23	483*	532	556	580	606	636	663	664	686	716	769	814	858
24	533*	533	557	581	607	637	663	665	686	718	771	815	860
25	533	534	557	582	608	638	663	666	686	720	773	816	862
26	531	534	557	583	609	639	663	667	686	722	775	818	863
27	530	535	558	584	610	640	663	668	686	724	778	820	864
28	528	536	559	585	611	641	663	669	686	725	777	823	865
29	526	536	560	585	612	642	..	670	687	726	777	824	867
30	524	537	561	586	613	643	..	671	687	728	778	825	869
31	522	..	562	..	614	644	..	672	..	730	..	826	870

* Aug. 5. 570 from 4 hr. Aug. 23. 483 from 2 hr.
,, 6. 430 ,, 3 hr. ,, 24. 533 ,, 3 hr.

occasion this was indeed done. In bridging short interval discontinuities in the standard H and Z records and in filling up gaps during times when these records were necessarily lacking owing to adjustments in progress with the standard variometers, the subsidiary instruments were frequently very useful. But as a means of verifying temperature coefficients, scale values, and trend of base line values in the standard instruments, the subsidiary set was not in practice helpful. The primary reason for this was that the H and Z variometers in the auxiliary set themselves had unknown and probably large temperature coefficients. They were never intended to be capable of replacing the standard instruments. Intentionally run at a very low sensitivity, approximately 50 γ/mm. for H and 40 γ/mm. for Z, their function was:

(i) To supply independent records on a small scale of the largest perturbations in the magnetic field, in case, through accident, the prism mechanisms for additional reflected traces of the standard set might be out of operation; and

(ii) To supply a means of interpreting unknown or uncertain parts of the standard record for short periods (of a few hours) during adjustment or accidental failures. Approximate scale values of the H and Z constituents of this auxiliary set were derived solely through those of the standard instruments by comparison of corresponding movements; no attempt was made to derive accurate temperature coefficients or to compute base line values.

§ 24. *D base line values.*—The matter was otherwise for the declination constituent of the auxiliary magnetograph; indeed, the procedure was completely reversed as compared with the force components. The Copenhagen declinometer had a scale value which was unalterable at 0·95′/mm. This resulted in an almost daily use of the reflected traces; during disturbance the recording of the greatest oscillations frequently brought the third and fourth reflected traces into action. The measurement of hourly values from such a record would have been a very great task. Hence, instead of using the D record of the standard Copenhagen magnetograph for the basic tabulations, the auxiliary D record running at a scale value of 2·09′/mm. was used, and the Copenhagen trace was referred to only during periods of uncertainty or complete lack in the auxiliary.

Apart from isolated excursions of the auxiliary D trace off the sheet, the only need for extensive use of the Copenhagen record occurred in the summer months of 1933. Then an insidious fungus growth, difficult to detect except by its occasional effect on the observed base line values, formed between the suspended system and the inside of the suspension tube. The growth was cleared away on several occasions, but promptly reappeared. It had probably some connection with the presence of shellac on a part of the magnet-mirror system, together with the very wet atmosphere and rising temperature in the chamber at that time. The result was that for three separate periods from June onwards the Copenhagen D trace had to supplant the auxiliary record in forming the basic D data.

During August 1932 the Kew magnetometer was used for determining the D base line values; for all the remaining twelve months the Smith magnetometer was the basic instrument. Defining Δ again as the difference between the observed and assigned base line values, the value of $\sqrt{\{\Delta^2/(n-1)\}}$ for the whole period of acceptance of the auxiliary D as the tabulated record based on the Smith magnetometer observations, that is, excepting August 1932, was $\pm$ 1·6′.

The method adopted in allotting base line values to the D records was similar to that used in the major portions of the H and Z records, viz. plotting the observed base line values and drawing a smooth curve through them. But, in addition, base line values were independently derived on the basis of the same absolute determinations for the Copenhagen instrument. Plotting of both sets of base line values and sample ordinates for selected pairs of quiet hours from as many days as possible throughout the year revealed surprising differences in their trends. This gave rise to considerable further examination before base line values for either instrument were finally accepted for use in the tabulations. Unlike the variometers which record force components, D variometers are not (or should not be) affected by temperature changes. The only essential difference between the auxiliary D and the Copenhagen D instruments, in addition to difference in scale value, was that, whereas the auxiliary D instrument recorded westerly declination, the other recorded easterly declination. But it was only a matter of arithmetic to relate the one directly to the other. It is, of course, true that two instruments of different design and characteristics, even though so apparently simple as declination variometers, and recording within a few metres of each other, seldom record exactly alike. Differences in momentum of the moving systems and characteristics of the suspension produce variations in behaviour which show up readily when, for example, ranges of corresponding movements in the two records are compared. The ratio of the ranges varies markedly with the type of movement. But though such differences were certainly noticeable in the Fort Rae

TABLE 9.—ADOPTED BASE LINE VALUES: D.

Greenwich Recorder: 40° + Tabulated Values.
Copenhagen Recorder: 36° + Tabulated Values in italics.

Date.	1932.					1933.							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
	′	′	′	′	′	′	′	′	′	′	′	′	′
1	−32·5	12·4	12·5	12·8	13·2	14·0	14·5	14·6	13·9	12·9	12·9	*38·6*	*38·9*
2	−32·5	12·4	12·5	12·8	13·2	14·0	14·5	14·5	13·9	12·8	12·9	50·0	*38·9*
3	−32·5	12·4	12·6	12·8	13·2	14·0	14·6	14·5	13·8	12·8	13·0	50·0	*38·8*
4	−32·5	12·4	12·6	12·8	13·3	14·0	14·6	14·5	13·8	12·7	13·0	50·0	*38·8*
5	12·3	12·4	12·6	12·8	13·3	14·0	14·6	14·5	13·8	12·7	13·0	50·0	*38·8*
6	12·3	12·4	12·6	12·8	13·3	14·0	14·6	14·5	13·8	12·7	13·0	50·0	*38·8*
7	12·3	12·4	12·6	12·8	13·4	14·1	14·6	14·5	13·7	12·6	*39·8*	50·0	*38·7*
8	12·3	12·4	12·6	12·8	13·4	14·1	14·6	14·4	13·6	12·5	*39·7*	50·0	*38·7*
9	12·3	12·4	12·6	12·8	13·4	14·1	14·6	14·4	13·6	12·5	*39·6*	50·0	*38·6*
10	12·3	12·4	12·6	12·9	13·4	14·1	14·6	14·4	13·6	12·4	*39·6*	50·0	*38·6*
11	12·3	12·4	12·6	12·9	13·5	14·2	14·6	14·4	13·6	12·4	*39·5*	50·0	*38·6*
12	12·3	12·4	12·6	12·9	13·5	14·2	14·6	14·4	13·5	12·3	*39·4*	*38·8*	*38·5*
13	12·3	12·4	12·7	13·0	13·5	14·2	14·6	14·4	13·5	12·3	*39·3*	*38·8*	1·0
14	12·3	12·4	12·7	13·0	13·6	14·2	14·6	14·3	13·4	12·3	*39·2*	*38·8*	1·0
15	12·3	12·4	12·7	13·0	13·6	14·2	14·6	14·3	13·4	12·3	*39·1*	*38·9*	1·0
16	12·3	12·4	12·7	13·0	13·6	14·2	14·6	14·3	13·4	12·3	*39·0*	*38·9*	1·0
17	12·3	12·4	12·7	13·0	13·6	14·2	14·6	14·2	13·3	12·3	*39·0*	*38·9*	1·0
18	12·3	12·4	12·7	13·0	13·6	14·3	14·6	14·2	13·3	12·4	*39·0*	*38·9*	1·0
19	12·3	12·4	12·7	13·0	13·7	14·3	14·6	14·2	13·3	12·4	*38·9*	*39·0*	1·0
20	12·3	12·4	12·7	13·0	13·7	14·3	14·6	14·2	13·2	12·4	*38·9*	*39·0*	1·0
21	12·3	12·4	12·7	13·0	13·7	14·3	14·6	14·2	13·2	12·4	*38·8*	*39·0*	1·0
22	12·4	12·4	12·7	13·1	13·7	14·4	14·6	14·1	13·2	12·5	*38·8*	*39·0*	1·0
23	12·4	12·4	12·7	13·1	13·8	14·4	14·6	14·1	13·2	12·5	*38·8*	*39·0*	1·0
24	12·4	12·4	12·8	13·1	13·8	14·4	14·6	14·1	13·1	12·5	*38·7*	*39·0*	1·0
25	12·4	12·4	12·8	13·1	13·8	14·4	14·6	14·0	13·1	12·6	*38·7*	*39·0*	1·0
26	12·4	12·4	12·8	13·1	13·8	14·4	14·6	14·0	13·0	12·6	*38·6*	*39·0*	*37·6*
27	12·4	12·4	12·8	13·1	13·8	14·4	14·6	14·0	13·0	12·6	*38·6*	*39·0*	*37·5*
28	12·4	12·4	12·8	13·2	13·9	14·5	14·6	14·0	13·0	12·7	*38·6*	*39·0*	*37·4*
29	12·4	12·5	12·8	13·2	13·9	14·5	..	14·0	12·9	12·7	*38·6*	*39·0*	*37·3*
30	12·4	12·5	12·8	13·2	13·9	14·5	..	14·0	12·9	12·8	*38·6*	*39·0*	*37·2*
31	12·4	..	12·8	..	13·9	14·5	..	13·9	..	12·8	..	*38·9*	*37·1*

D magnetographs they could have little or no effect on such mean values as go to provide base line values. Since the major discrepancies were more pronounced in the months June to August 1933 it is more likely that the major cause of the discrepancies is to be traced to the circumstances described in § 16.

The procedure actually adopted was to fit the line from which were deduced the base line values to be employed for the auxiliary variometer in such a way that the sets of base line values claimed by the separate instruments were neither of them seriously outraged. At the time of use of the Copenhagen record to fill up periods of uncertainty in the functioning of the auxiliary D in June to August 1933, not only was attention given to this mutually consistent run of base line values, but care was also taken to see that the tabulated values from corresponding sets of hours at the times of discontinuity were in good agreement.

The declination base line values finally adopted for purposes of tabulation are given in Table 9. For all days except those specifically indicated as having been derived from the Copenhagen variometer the values refer to the records from the Greenwich instrument. Although the declination trace from the Copenhagen magnetograph was used as indicated above, it has been considered advisable to keep the data from this magnetograph complete. To this end the complete set of base line values for the Copenhagen D instrument are given in Appendix III.

§ 25. *Monthly mean values: the annual variation and secular change.*—Tables 160 to 211 in Vol. II, excluding every fourth table in that set, give the hourly values for each of the three primary elements H, D, and Z derived from the curve measurements. These values are means over 60-minute periods centred at the half-hour G.M.T. The daily means are simply 1/24th of the sum of the 24 values covering the period between successive Greenwich midnights. The tables are complete for every hour of the thirteen months in H, but lack April 2 in D and April 1–4 in Z. The explanation of the loss of these days is as follows: To save water in the process of developing the charts it was our practice to store the records taken off each day for development twice a week. Immediately prior to a development in early April, the lid from a box containing the accumulated records from all the magnetographs came off, exposing the undeveloped records to bright sunlight. All records were badly fogged, some so badly that it has not been possible to read them.

Table 10 summarises the monthly and seasonal mean values of the elements derived from the daily means of *all* days in Table 160, *et seq.*, of Vol. II, the year in this and all similar tables being made up of the thirteen months combined in the following way:—

$$\text{Year} = \tfrac{1}{12}\{\tfrac{1}{2}(\text{August 1932} + \text{August 1933}) + \text{September} + \text{October} + \ldots + \text{June} + \text{July}\}.$$

The two Augusts are treated similarly in the formation of a representative summer value.

TABLE 10.—MEAN VALUES OF H, D, AND Z FROM HOURLY VALUES ON ALL DAYS.

Element.	1932.					1933.								Winter.	Equinox.	Summer.	Year.
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.				
H 7000 γ + .	731·1	720·0	725·4	730·4	726·8	736·0	731·3	727·0	732·2	740·4	750·9	755·9	737·5	731·5	726·1	745·4	734·2
D 37° + . .	34·3′	36·1′	35·4′	34·2′	34·3′	33·1′	33·1′	32·9′	30·3′	26·6′	24·8′	23·3′	23·9′	33·7′	33·7′	25·9′	31·1′
Z 59,000 γ + .	955·0	943·4	969·5	963·8	955·5	942·4	949·0	947·3	957·1	951·0	957·2	955·4	977·9	952·7	954·3	957·5	954·8

For the year so formed the average value of H is 0·07734 Γ, of D 37° 31·1′ E., and of Z 0·59955 Γ.

Monthly mean values derived from observations covering such a short period cannot be considered adequate for conclusive decisions about the annual change in the elements. As will be seen presently, disturbance of the magnitude commonly experienced at Fort Rae can decrease the value of H on individual disturbed days as compared with neighbouring quiet days by amounts of the order of 100 γ. Mean values derived from a single month are therefore largely determined by the presence or absence of disturbance during that month. When the seasonal mean values in Table 10 are compared with those in Table 4, corrected (approximately) for the daily variation at the time of day at which the control observations were made (Table 5 and § 13), and again with the mean values from all days of the 1882–83 expedition to the Old Fort Rae site, some common features pointing to facts of significance in the annual variation of the elements emerge. These seasonal means are summarised in Table 11. For the purpose of this comparison and in view of a subsequent use to be made of it, a new summer s_{33} has been formed for the 1932–33 data by excluding August 1932.

The last line of Table 11, showing the excess of the summer over the winter mean values, makes it clear that, whether derived from the magnetograms on all days in 1932–33, or from the control observations in that year, or from the hourly readings of the variometers in 1882–83, H and Z tend to be higher and easterly declination less in summer than in winter. As is to be expected, the values of the difference (summer–winter) vary widely with the mode of derivation, the variation being greatest in Z and least in D. The most comparable are the *s–w* differences for H and D from the first and third sections of the table.

TABLE 11.—SEASONAL MEAN VALUES, ALL DAYS, 1932–33 AND 1882–83.

Season.	1932–33.									1882–83.		
	Derived from Magnetograms.			From Control Observations Uncorrected for Diurnal Variation.			From Control Observations Corrected for Diurnal Variation.			From Hourly Eye Readings.		
	H 7000 γ +	D 37° +	Z 59,000 γ +	H 7000 γ +	D 37° +	Z 59,000 γ +	H 7000 γ +	D 37° +	Z 59,000 γ +	H 7000 γ +	D 40° +	Z 61,000 γ +
	γ	′	γ	γ	′	γ	γ	′	γ	γ	′	γ
y	734	31·1	955	745	23·0	948	732	30·2	958	649_5	$22{\cdot}6_5$	778
w	731	33·7	953	738	26·4	936	728	32·9	954	635	24·7	751
e	726	33·7	954	747	24·5	944	724	33·5	951	646	24·9	800
s_{33}	746	$24{\cdot}6_5$	960	749	18·2	965	743	24·1	970	667	$18{\cdot}3_5$	782
s–w	+15	−9·0	+7	+11	−8·2	+2·9	+15	−8·8	+16	+32	−6·3	+31

The real significance of this summer excess cannot readily be decided. It is made up partly of real secular change and partly of real annual change if such exists. Since, in the data from both years in Table 11, the winter and summer values are centred approximately at January 1 and July 1 respectively of the same year, a complete absence of an annual inequality in the monthly values would allow the *s–w* difference to be taken as a measure of half the annual secular change, assuming this change to be uniform throughout the year. On this basis the annual secular change derived from the all-day magnetogram means for 1932–33 would be $+30\ \gamma$, $-18{\cdot}0'$, and $+14\ \gamma$ for H, D, and Z respectively. But Table 10, in giving individual monthly mean values for 1932–33, supplies by comparison of the means for August 1932 and August 1933 the differences $+6\ \gamma$, $-10{\cdot}4'$, and $+23\ \gamma$ as alternative estimates of the annual secular change for the three primary elements: the directions of change are the same, but quantitatively they differ widely.

The difficulty in estimating the secular change from one year's data lies in the fact that the secular change cannot be disentangled from the effect of disturbed and quiet conditions on the mean value of the field. Table 12 illustrates this by giving the mean values on two sets of days selected by the combined criteria of $(HR_H + ZR_Z)\,.\,10^{-4}$ and $(Hr_H + Zr_Z)\,.\,10^{-4}$ (§§ 71 and 72) as being the 38 quietest and 40 most disturbed days during 1932–33. Comparing the values in this table with those for all days (Table 11) we see that on the quietest days H exceeded the all-day value by 25 γ, while the depression of H on the most disturbed days amounted to 84 γ. For any one month the mean value of H is therefore a function of the magnetic activity in that month, and this may be wholly independent of the position of the month in the year. Judged by the mean values of the international character figures, April, September, October, and March in that order were the most disturbed months of the Polar Year, and at the other end the five quietest months were May, August (1933), November, June, and July.

Therefore, with equinox the most disturbed and summer the quietest season, we should expect to find equinox and summer at opposite ends of the seasonal scale of mean H even if H had no annual variation. This is, indeed, what the all-day figures in the first section of Table 11 show. For the element H (and similar arguments hold for D and Z) we must therefore conclude that the prevalence or absence of disturbance has too great an effect on the mean values of individual months to allow real deductions to be made from the present data about the reality of an annual variation, and the same effects make uncertain any decisions about even the direction of the secular change.

TABLE 12.—SEASONAL MEAN VALUES ON QUIETEST (q') AND MOST DISTURBED (d') DAYS.

Season.	H.		D.		Z.	
	q'.	d'.	q'.	d'.	q'.	d'.
	7000 γ +		37° +		59,000 γ +	
	γ	γ	′	′	γ	γ
y	759	675	29·6	36·8	944	977
w	755	669	31·6	40·6	944	969
e	757	667	31·0	38·1	938	974
s	764	689	26·1	31·6	950	987

The natural sequel to the foregoing paragraphs is to inquire what light is thrown on the two phenomena there discussed by considering mean values derived from days selected as being all of one class, either quiet or disturbed. Information on this is given in Table 13, which shows the monthly mean and seasonal values based on the five quiet (q) and five disturbed (d) days per month selected by the international scheme of characterisation for 1932–33 and from representative quiet days (about four per month) of 1882–83. In this table s_{23} is the mean summer derived from $\frac{1}{4}\{\frac{1}{2}$(August 1932 + August 1933) + May + June + July$\}$, and s_3 is derived from the four summer months of 1933 (or 1883) alone.

Considering first the 1932–33 seasonal quiet day means, we see that the directions of change from midwinter to midsummer in H, D, and Z remain the same as for all days, but that the magnitudes are halved, $+8\,\gamma$ for H, $-7{\cdot}7'$ for D, and $+3\,\gamma$ for Z. In H the mean equinox value is now brought up between the winter and s_3 values. The q day means for 1882–83, in the third section of the table, show directions in all three elements similar to these for 1932–33 and for the all-day means for the earlier year, the changes from midwinter to midsummer values being $+10\,\gamma$ for H, $-4{\cdot}0'$ for D, and $+43\,\gamma$ for Z.

When account is taken of the differences in method by which the 1882–83 and the 1932–33 results were obtained, these figures are conclusive only in showing that if there is a real annual variation in the elements at Fort Rae, the directions are as given, but the true values of the magnitude of the change are not so easily decided. For while the 1932–33 d day means in Table 13 show that the directions of change from midwinter to midsummer in all elements are the same for these d days as for all and q days for both years, the magnitudes are increased to $+26\,\gamma$ for H, $-10{\cdot}7'$ for D, and $+15\,\gamma$ for Z. As will be seen later in a study of the diurnal variations, a residue of disturbance persists even on the quietest days at Fort Rae. It is therefore entirely questionable what would remain of the $+8\,\gamma$, $-7{\cdot}7'$, and $+3\,\gamma$ for the H, D, and Z quiet-day six-monthly change if conditions on these q days in 1932–33 had been more quiet than in fact they were. In this connection it is of interest to note that in the specially selected classes of quietest and most disturbed days (Table 30) the directions of change from winter to summer in all three components are the same as those for the general classes discussed above.

Had there been a greater number of common months, light might have been shed on the problem from a different angle. As it is, with only one August of each year common, the material is inadequate to afford a measure of the secular change and to allow the residue to be attributed to annual variation. Too much depends on the relative quietness of the quiet days in these two months. A more satisfactory way is to assume that during 1932–33 the secular change, if it existed, was uniform throughout the year, and to take as its measure the average trend from a graphical representation of the 13 quiet-day monthly mean values. This procedure leads to the following values of the annual secular change: $+9\,\gamma$ for H, $-10{\cdot}0'$ for D, and $+6\,\gamma$ for Z. From pure secular change alone, the change in the values of the elements from midwinter to midsummer should be one-half these quantities. We

TABLE 13.—MONTHLY MEAN VALUES OF MAGNETIC ELEMENTS ON INTERNATIONAL QUIET AND DISTURBED DAYS, 1932–33, AND QUIET DAYS, 1882–83.

Month and Season.	1932–33.						1882–83.		
	Quiet Days.			Disturbed Days.			Quiet Days.		
	H.	D.	Z.	H.	D.	Z.	H.	D.	Z.
	$7000\,\gamma+$	$37^\circ+$	$59{,}000\,\gamma+$	$7000\,\gamma+$	$37^\circ+$	$59{,}000\,\gamma+$	$7000\,\gamma+$	$40^\circ+$	$61{,}000\,\gamma+$
	γ	$'$	γ	γ	$'$	γ	γ	$'$	γ
August	762·8	33·4	938·4	688·9	35·8	986·7	..	..	..
September	751·9	33·6	922·4	676·7	42·4	979·2	641	32·5	791
October	753·5	32·5	953·8	673·2	41·8	1008·4	662	26·5	752
November	754·5	32·0	958·6	696·4	36·4	991·0	675	27·8	704
December	744·5	32·0	954·4	681·1	39·3	954·7	666	20·3	716
January	750·8	32·3	937·3	729·9	33·3	938·4	656	19·5	759
February	753·7	30·6	940·8	686·6	39·7	969·8	670	15·8	734
March	748·8	30·1	942·0	708·2	37·5	931·1	667	15·3	774
April	755·5	27·8	946·7	720·0	32·4	958·7	676	13·9	806
May	752·9	26·0	937·7	718·9	29·8	982·0	675	16·0	779
June	761·1	24·4	954·5	738·4	23·7	946·8	686	14·6	785
July	759·5	22·9	951·7	739·6	25·7	983·3	673	16·8	766
August	761·6	22·8	958·5	703·0	26·9	1002·0	680	19·3	753
w	750·9	31·7	947·8	698·5	37·2	963·5	668	20·8	728
e	752·4	31·0	941·2	694·5	38·5	969·3	661	22·0	781
s_{23}	758·9	25·3	948·1	723·2	27·6	976·6	..	..	..
s_3	758·8	24·0	950·6	725·0	26·5	978·5	678	16·8	771
y	754·1	29·4	945·7	705·4	34·4	969·8	669	19·9	760

are therefore left with residues of $+3{\cdot}5\,\gamma$ for H, $-2{\cdot}7'$ for D, and no change for Z, as the possible differences between summer and winter mean values on the basis of the 1932–33 q days. Since 1 minute of arc in D represents only $2{\cdot}25\,\gamma$ in force units transverse to the meridian, the only reasonable deduction to be made from this result is that, whatever annual variation in the elements may exist at Fort Rae, its seasonal range is very small, probably much below $5\,\gamma$ in all directions of the field on the quietest days obtainable in that very disturbed region.

§ 26. *Monthly and seasonal mean values of N, E, T, I, and A.*—From the monthly mean values of the primary elements H, D, and Z derived from the magnetogram readings on all days, corresponding monthly and seasonal values have been computed for the two orthogonal components N and E, for total force T, and for inclination I. These values are given in Table 14, to which is also added a column showing the monthly and seasonal values of A, the component of the field parallel to the earth's rotation axis derived from $N\cos\phi - Z\sin\phi$, where ϕ is the latitude of Fort Rae

(62° 49′ 46″). Of the two components of A, that determined by Z sin ϕ always predominates. A is therefore always negative, *i.e.* the component parallel to the earth's axis is always directed towards the south geographical pole.

In view of the detailed analysis of the annual variation of the primary elements already described in § 25, the results of Table 14 require little further comment. As also at such observatories as Lerwick and Eskdalemuir, the mean force across the meridian at Fort Rae is the steadiest of the three components. From the month of highest E value (January) to the lowest (August 1933) the range at Fort Rae was 16 γ. Since T is so little larger than Z—T for the year is 60,452 γ compared with 59,955 γ for Z—the month to month variation in T is overwhelmingly determined by that of Z, which has already been examined. The relation between N and H is even closer than that between T and Z, so the annual change of N is very similar to that of H.

TABLE 14.—MEAN MONTHLY AND SEASONAL VALUES OF DERIVED ELEMENTS.

Month and Season.	N.	E.	T.	I.	A.
	γ	γ	γ	° ′	γ
1932 Aug.	6127	4714	60451	82 39·1	−50541
Sept.	6116	4711	60438	82 39·7	−50536
Oct.	6119	4712	60464	82 39·6	−50557
Nov.	6127	4713	60460	82 39·3	−50549
Dec.	6124	4712	60451	82 39·4	−50542
1933 Jan.	6133	4715	60439	82 38·8	−50527
Feb.	6129	4712	60445	82 39·1	−50535
Mar.	6126	4709	60443	82 39·3	−50535
Apr.	6134	4707	60453	82 39·1	−50540
May	6145	4706	60449	82 38·6	−50530
June	6156	4709	60456	82 38·0	−50530
July	6162	4710	60455	82 37·7	−50525
Aug.	6150	4699	60475	82 39·0	−50553
y	6134	4710	60452	82 39·0	−50538
w	6128	4713	60449	82 39·1	−50540
e	6124	4710	60450	82 39·4	−50541
s	6150	4718	60455	82 38·4	−50533

§ 27. *Comparison observations at the 1882–83 (Old Fort) station.*—The site occupied by the 1882–83 expedition lay some 15 miles to south-east of the 1932 base, on the crescent-shaped promontory known to the Indians as Nu-chié, or, since the transfer of the settlement to the present site, as the Old Fort. To determine the secular change in the magnetic elements in the fifty years since the First Polar Year, it was desirable to make a series of observations of H, D, and I on a site as near as possible to that used by Captain Dawson in 1882. The plan of the Old Fort locality (fig. 2) showing the probable position of that site and the existing features indicates that our repeat observations were made within 120 metres of those of fifty years ago.

Although the Old Fort was occupied as a substation intermittently throughout the entire 13 months, most of the observations were made during two periods of occupation: one in September 1932, the other in June and July 1933. During the winter months there was not only ample other routine work in connection with the auroral photography at the substation, but conditions were too rigorous for a protracted series of observations in the tent under cover of which the summer observations were made.

The instruments used for determining the value of the magnetic elements at the substation were:—

(i) Kew magnetometer, Dover No. 140; and
(ii) Dip circle, Dover No. 120.

§ 28. *Determination of horizontal force at Old Fort Rae.*—For several reasons which need not be detailed, it was considered inadvisable to transport to the substation the Smith magnetometer, which was the standard of reference for the continuous registrations at the main base. The secular change at the substation had therefore

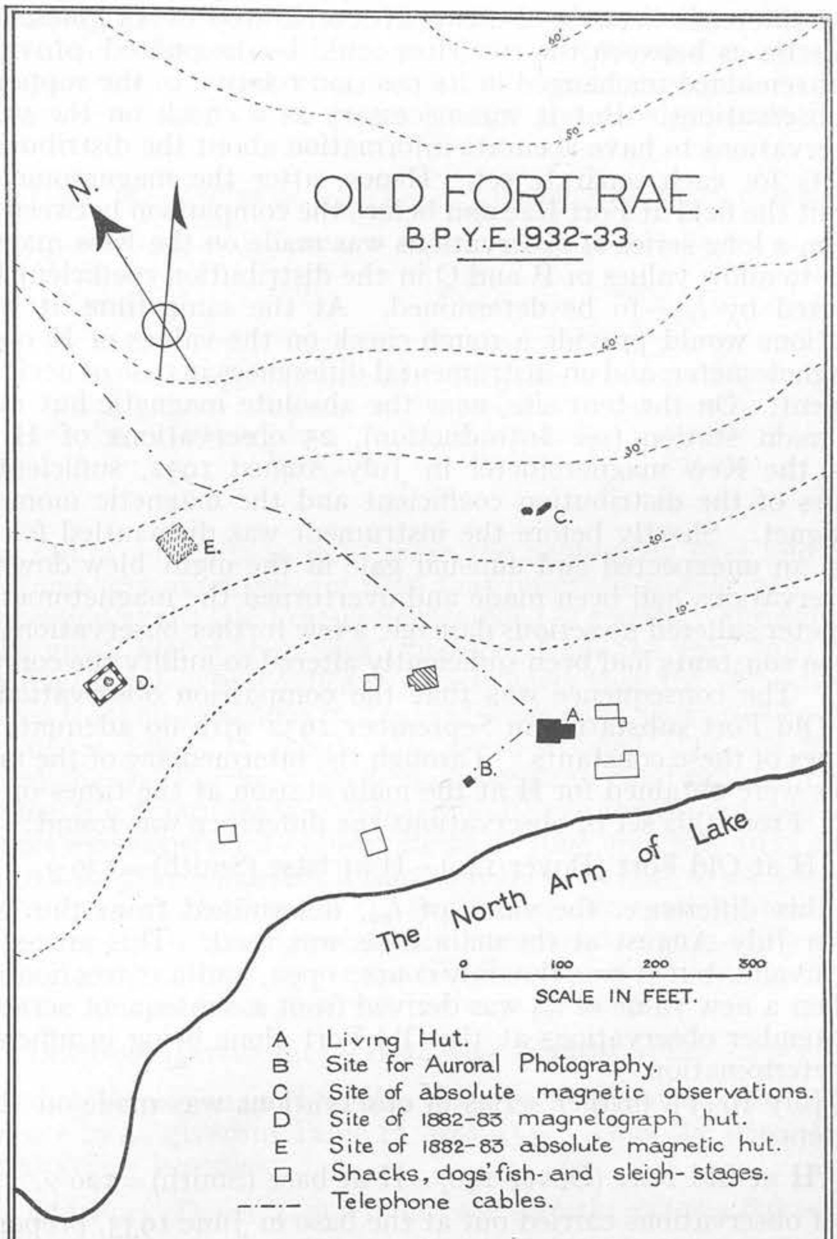


FIG. 2.

to be determined through the intermediary of another magnetometer, and, since the measure of the secular change was to be based on the mean value of the elements at the main station over the whole year, this necessitated the determination of two quantities:—

(i) The instrumental difference between the two magnetometers; and

(ii) The site difference in H between the 1932–33 base and that of 1882–83.

Unlike the electromagnetic type of magnetometer, the Kew pattern magnetometer used in the comparison alters its constants with locality. If the moment of inertia of the oscillating magnet with its carriage, and the values of the distribution constants (P, Q) for the deflecting and deflected magnets have been determined with the magnets balanced for a locality in which the inclination is, say, 66°, as in the neighbourhood of London, these values will not obtain after the magnets have been re-arranged to suit an inclination of 82°. Since the magnetometer was to be used primarily to determine the difference between the two sites separated by 15 miles, the change in moment of inertia as between the two sites could be discounted, provided the collimator magnet remained unchanged in its position relative to the support during the comparison observations. But it was necessary as a check on the validity of the groups of observations to have accurate information about the distribution constants of the magnets for each separate set. Hence, after the magnetometer had been arranged to suit the field at Fort Rae and before the comparison between the two sites was entered on, a long series of observations was made on the Kew magnetometer at the main base to allow values of P and Q in the distribution coefficient $\log_{10}(1+P/r^2+Q/r^4)$—denoted by l_{PQ}—to be determined. At the same time, it was reasoned, these observations would provide a rough check on the values of H observed using the Smith magnetometer, and on instrumental differences in case of accident to one or other instrument. On the tent site, near the absolute magnetic hut marked in the plan of the main station (see Introduction), 25 observations of H were therefore made on the Kew magnetometer in July–August 1932, sufficient to produce accurate values of the distribution coefficient and the magnetic moment m of the collimator magnet. Shortly before the instrument was dismantled for transport to the substation an unexpected and unusual gale in the night blew down the tent in which the observations had been made and overturned the magnetometer. Though the magnetometer suffered no serious damage, a few further observations showed that the distribution constants had been sufficiently altered to nullify the comparison work already done. The consequence was that the comparison observations had to be begun at the Old Fort substation in September 1932 with no adequate information about the values of these constants. Through the intermediary of the magnetograph records, values were obtained for H at the main station at the times of the Old Fort observations. From this set of observations the difference was found:

$$\text{H at Old Fort (Dover 140)} - \text{H at base (Smith)} = 130\,\gamma.$$

To establish this difference, the value of l_{PQ}, determined from the long series of observations in July–August at the main base, was used. This procedure was now known to be invalid, but it was the only course open, and a correction could readily be applied when a new value of l_{PQ} was derived from a subsequent series of observations, the September observations at the Old Fort alone being insufficient to give a satisfactory determination.

In June–July 1933 a further series of observations was made on the same site, giving a difference:

$$\text{H at Old Fort (Dover 140)} - \text{H at base (Smith)} = 120\,\gamma.$$

A series of observations carried out at the base in June 1933, preparatory to the second comparison set at the Old Fort, gave a difference:

$$\text{H by Smith} - \text{H by Dover 140 (both at main base)} = 18\,\gamma.$$

All determinations had been obtained using the value of l_{PQ} derived from the July–August observations at the base. When values of this quantity were computed from the separate series of observations made in September 1932 and in the following summer, the results shown in Table 15 were obtained.

These indicated that not only had the distribution constants been substantially altered when the instrument was overturned in the damage to the tent during the gale of 1932 August 29, but that another change had appeared between the September 1932 and the June 1933 observations. The observations at the base and at the Old Fort station in 1933 gave substantially consistent values of the quantity l_{PQ}. This was borne out by the values of m, the magnetic moment of the collimator magnet.

Using the July–August 1932 values of l_{PQ} throughout, the values of m for sets 2, 3, and 4 in Table 15 were 590·6, 588·0, and 587·7 C.G.S. units respectively.

Now if, instead of using the July–August 1932 values of l_{PQ}, the values of this quantity derived from the sets of observations Nos. 3 and 4 were used, an increase of 6·1 units in m, with a reduction of 79 γ in H, would be entailed in set No. 3 and, in the same directions, 6·3 units in m and 83 γ in H for set No. 4. These changes in m would bring the final mean values of m in June and July 1933 to 594·1 and 594·0 respectively. To take corresponding account of l_{PQ} for September 1932 required an increase of m in the observations of that month to 599·9 units and a reduction in H of 126 γ.

TABLE 15.—VALUES OF $\log_{10}\left(1+\frac{P}{r^2}+\frac{Q}{r^4}\right)$ FROM KEW MAGNETOMETER.

Set Number.	Date.	Place of Observation.	$\log_{10}\left(1+\frac{P}{r^2}+\frac{Q}{r^4}\right)$.
1	1932 July–August	Main base	$\bar{1}$·99974
2	September	Old Fort	$\bar{1}$·98583
3	1933 June	Main base	$\bar{1}$·99082
4	June–July	Old Fort	$\bar{1}$·99049

Now the fall of 5·9 units in m between the September 1932 and the June–July 1933 observations was much greater than that observed to take place at the time of the last observation at the Old Fort in September ($\simeq$ 3 units); the adjusted m (599·9) would also be much higher than that computed from the July 1932 observation at the main station ($\simeq 596\,\gamma$) and only 2 to 3 units lower than the value of m for the same magnet derived from observations in England some eight years earlier (see *Geo. Mem.*, No. 30, vol. iii, p. 278). It should also be mentioned that the September 1932 observations at the Old Fort were made under difficult conditions and were limited in number, so that the determination of l_{PQ} cannot have the same value as that for the more consistent and satisfactory observations of June and July 1933 at the base and substation. All things considered, it has been thought best to use such a value of l_{PQ} as would result in a reasonable m for the September observations, taking into account its value before that month, and its value as determined in 1933. This led to reducing H as determined by the Dover 140 at the Old Fort in September 1932 by 93 γ, so that the difference for this series of observations now becomes:

$$\text{H at Old Fort (Dover 140)} - \text{H at base (Smith)} = (130 - 93)\ \gamma = 37\ \gamma.$$

The corresponding reduction in H for the June–July 1933 observations, brought about by the difference in l_{PQ} given in Table 15, was 83 γ. Thus the site difference for this series of observations becomes:

$$\text{H at Old Fort (Dover 140)} - \text{H at base (Smith)} = (120 - 83)\ \gamma = 37\ \gamma.$$

But a similar adjustment is necessary for the fact that in the observations of June 1933 by the Dover magnetometer at the main base the value of l_{PQ} July–August 1932 was used. On this account the correction to the value of H obtained by the Dover magnetometer is $-79\,\gamma$.

Thus the instrumental difference becomes:

$$\text{H at base (Smith)} - \text{H at base (Dover)} = 18 - (-79)\ \gamma = 97\ \gamma.$$

Thence the site difference in 1932–33 obtained, using all comparison observations, becomes:

$$\text{H at Old Fort} - \text{H at base} = 134\ \gamma.$$

It will be noted that the need for the adjustments described in preceding paragraphs has been necessary merely to justify the observations of September 1932 and to bring the uncertain *m* of the collimator magnet as determined by the results then obtained into alignment with its value before and after.

A simpler method of determining the site difference in H would have been to reason that the observations of June–July 1933 alone give sufficiently consistent results to warrant the whole burden of comparison being laid on them. On this basis the absolute value of l_{PQ} is of no importance so long as it does not change within the limited time of the comparison. All that is then necessary is to take the difference for June 1933:

$$\text{H (Smith) base} - \text{H (Dover) base} = 18\ \gamma,$$

along with the difference:

$$\text{H (Dover) Old Fort} - \text{H (Smith) base} = 120\ \gamma,$$

obtained immediately after, the values for the moments of the collimator magnet for the two sets differing by only 0·3 units. Thus the site difference becomes:

$$\text{H at Old Fort} - \text{H at base} = 138\ \gamma.$$

If the two values of l_{PQ}, $\bar{1}$·99082 for June and $\bar{1}$·99049 for July, are taken into account, the site difference reduces to 134 γ and the moments differ by only 0·1 units. Since this agrees exactly with the value obtained by using all comparison observations it is accepted as the site difference in 1932–33.

§ 29. *Determination of declination at Old Fort Rae.*—Observations of D were made on the same site as H at the Old Fort and at times usually either immediately following or immediately before these of H, both in September 1932 and in the summer of 1933. Normally a more straightforward element to deal with, torsional factors in the silk suspension used in the Kew magnetometer introduced uncertainties, particularly in 1933. The determination of the azimuth of the fixed mark used in the observation—a conspicuous spruce tree on an island about 1 km. distant from the declinometer site—also gave rise unexpectedly to an extensive series of determinations of the longitude of the Old Fort. This was necessary after a confirmatory determination showed that the published value of the longitude of the site of the 1882–83 expedition differed from the true value by 4′ 51″. This matter is separately discussed in § 32.

All the declination observations in the summer of 1933 at the Old Fort gave a difference:

$$\text{D at Old Fort} - \text{D at base} = 17{\cdot}9',$$

but for those observations in this set of comparisons which were least affected by uncertainties due to residual torsion in the suspension the difference was 16·6′. On the other hand, the same difference as determined from the September 1932 observations was 16·8′. Hence 16·7′ is accepted as the excess of easterly declination at the Old Fort over that at the main base.

§ 30. *Determination of inclination at Old Fort Rae.*—The comparison of I at the Old Fort and base is based primarily on a double set of observations made in the summer of 1933. Observations were also made in September 1932, but, owing to a departure from the usual dip circle technique, values of I were obtained which could not be utilised. Unfortunately, too, it was not possible to make a direct comparison at the base between the values of I provided by the dip inductor used there as the standard instrument and the circle. The local value of I caused the needle to take up such a position that it could just not be observed. Very slight modifications were made in the supports of the circle just sufficient to allow the needle positions to be determined at the Old Fort in good light, since I there was some 8′ less than at the base. Without radical change in the dip circle and agate edge mountings it was not possible to observe I directly at the base. It must, therefore, be assumed that the circle and the inductor agreed, since comparison observations at some other angle of dip, as, for example, in England, would give no clue to the behaviour of the dip circle at Fort Rae, where different parts of the axle of the needles and the agate bearings would be in contact. From the margin by which the needles could just not be observed it was estimated that the dip circle and inductor differed, if at all, by an amount which probably did not exceed 2′.

Between June 27 and July 4, 1933, an extensive series of dip observations was carried out at the Old Fort. Subsequently from August 9 to 13 another series was made. Both series were in themselves consistent but differed from each other in the mean by 1′. Considering the type of instrument used and conditions of observation, it was decided to regard the two series as equally valid. The result therefore is that:

$$\text{I at main base} - \text{I at Old Fort sub-station} = 7{\cdot}8'.$$

§ 31. *Secular change at Old Fort Rae.*—Using the values of the difference (Old Fort − base) now established for the three magnetic elements in 1932–33, it is an immediate step to relate the mean values of these elements as obtained from the magnetographs at the main base to what they would have been had the 1882–83 site been used for magnetic recording during the whole year and hence to deduce the fifty-year secular change. The results are given in Table 16.

TABLE 16.—VALUES OF THE ELEMENTS NEAR THE 1882–83 SITE.

	D (east).	H.	I.	Z.	N.	E.	T.
	° ′	γ	° ′	γ	γ	γ	γ
1882–83 . .	40 22·7	7649	82 56·5	61778	5827	4955	62250
1932–33 . .	37 47·8	7868	82 31·2	59923	6217	4822	60438
Change in 50 years	− 2 34·9	+ 219	− 0 25·3	− 1855	+ 390	− 133	− 1812
Annual rate . .	− 0 3·1	+ 4·3	− 0 0·5	− 37·1	+ 7·8	− 2·7	− 36·2

It should be said that the entries in the last line of Table 16, showing the estimated annual rate of change, are of very questionable significance. The mode of derivation necessarily assumes a uniform and unidirectional change in all elements throughout the entire period of fifty years, an assumption for which there is little support in other localities.

§ 32. *Longitude of the Old Fort Rae site.*—The exact co-ordinates of the substation were required for determining:

(i) The azimuth of the fixed mark used in the observations of declination; and
(ii) The length of the base line used in auroral photography.

Since both the magnetic observations and auroral photography were carried out at a short and known distance from the site used by Captain Dawson in 1882 for his determinations of longitude by transit circle, it had been intended to use the longitude as then determined 115° 43′ 50″ W., with suitable correction for slight difference in site. It was noted, however, that the longitude of the Old Fort settlement, as given on a map issued by the Canadian Topographical Survey (and apparently determined independently by the Canadian surveyors), differed from Captain Dawson's longitude by an amount which agreed with that necessary to explain some discrepancies which had appeared in the determination of the azimuth of the fixed mark for declination observations.

A series of eight independent determinations of longitude was therefore made, the result of which was to confirm that the true longitude of the Old Fort station should be 115° 48′ 41″ W., this differing by 4′ 51″ from the 1882 determination.

§ 33. *Azimuth of fixed mark at Old Fort Rae.*—The fixed mark used in the declination observations was a small but prominent spruce tree on an islet in the Great Slave Lake about 1 km. approximately south-west of the tent site used for the observations. A very consistent series of observations by east and west altitude of the sun gave its azimuth as 230° 27′ 14″.

§ 34. *Relationships between all, quiet, and disturbed day values of the elements at the main station.*—Table 17 shows the excesses of the all and disturbed d day mean values over the quiet q day values, the q and d days being the Greenwich days (five per month) of the international scheme. The seasonal means in the table give the broad results: in view of the great diversity of character of individual days within the classes of q and d days, it is noteworthy that only three of the 78 contributing monthly values (one in D and two in Z) differ in sign from their seasonal means.

The effect of disturbance on H is much more pronounced than on the other elements. On the average of the 65 selected d days in the 13 months, disturbance depresses H relative to the q day value by 49 γ. In October 1932 (five days) this depression amounted to 80 γ. The apparent fall in the $q-d$ excess for H from e through w to s probably reflects the order of arrangement of the seasons in average disturbance (§ 86).

TABLE 17.—EXCESS OF ALL (a) AND DISTURBED (d) OVER QUIET (q) DAY MEAN VALUES, 1932–33.

Month and Season.	$a-q$.			$d-q$.		
	H.	D.	Z.	H.	D.	Z.
	γ	′	γ	γ	′	γ
1932 Aug.	−32	+1	+17	−74	+2	+48
Sept.	−32	+3	+21	−75	+9	+57
Oct.	−28	+3	+16	−80	+9	+55
Nov.	−24	+2	+ 5	−58	+4	+33
Dec.	−18	+2	+ 1	−63	+7	0
1933 Jan.	−15	+1	+ 5	−21	+1	+ 1
Feb.	−22	+3	+ 9	−67	+9	+29
Mar.	−22	+3	+ 5	−41	+7	−11
Apr.	−23	+3	+10	−35	+5	+12
May	−13	+1	+13	−34	+4	+44
June	−10	0	+ 3	−23	−1	− 8
July	− 4	0	+ 4	−20	+3	+32
Aug.	−24	+1	+19	−59	+4	+45
y	−20	+2	+ 9	−49	+5	+24
w	−20	+2	+ 5	−52	+3	+16
e	−26	+3	+13	−58	+7	+28
s	−13	+1	+ 9	−36	+2	+29

The effect of disturbance on D is small (5′ for the year) and in the direction of increasing easterly declination. In terms of force units, the average increase of force transverse to the meridian during disturbance, and referred to q day conditions, is only 12 γ compared with the 49 γ decrease in the meridian field. Though in the same direction in all seasons, the extent of winter and summer increases in transverse force during disturbance are almost negligible.

Acting in the opposite direction to that in H, disturbance increases Z to only half the extent of the effect on H on the year's average. In Z the greatest effect of disturbance in increasing the field is in summer and least in winter. This is probably attributable to the seasonal shift in mean position of the current system responsible for disturbance.*

Table 18 shows how the magnetic field is affected when the disturbance is more severe, and the quiet conditions quieter than those illustrated by the figures in Table 17. The days contributing to this table are those already referred to in § 25. The effects are most clearly seen when the d' day means of the elements are referred

* London, *Proc. Roy. Soc.*, A, 152, pp. 277–298 (1935).

to the q' means, but the increased value of $d' - q'$ compared with $d - q$ is more due to increased effect of the disturbance than to the greater purity of the quiet. For example, compared with all days, H on q' is only 5 γ higher than on q days, but $q' - d'$ is 84 γ compared with 49 γ for $q - d$.

TABLE 18.—EXCESS OF ALL (a) AND MOST DISTURBED (d') DAY MEAN VALUES OVER QUIETEST DAY (q') MEAN VALUES.

Season.	$a - q'$.			$d' - q'$.		
	H.	D.	Z.	H.	D.	Z.
	γ	′	γ	γ	′	γ
y	−25	+1·5	+11	−84	+7·2	+33
w	−24	+2·1	+ 9	−86	+9·0	+25
e	−21	+2·7	+16	−90	+7·1	+36
s	− 9	−0·2	+ 8	−75	+5·5	+37

§ 35. *Non-cyclic change.*—In the derivation of monthly mean diurnal inequalities of H, D, and Z for all days, and for the groups of five days each month selected as representing quiet and disturbed conditions, a correction has been applied to make the resultant variations periodic within the two Greenwich midnights defining the selected days. The elimination of the aperiodic element in the mean variation required a measure of the change in each element between the two Greenwich midnights between which the inequality was comprised, and since hourly mean values centred at each Greenwich half-hour have been used as the bases of tabulation, this change was taken as

$$\tfrac{1}{2}\{[24]+[1]\}_1 - \tfrac{1}{2}\{[24]+[1]\}_2,$$

where $\{[24]+[1]\}_1$ represents the sum of the hourly mean values immediately before and after the first midnight. The correction applied to eliminate this aperiodic change has been assumed to be uniform throughout the day. The average values of the change for each month, for each element, and for the three groups of days are shown in Table 19.

Though eliminated primarily to make the corrected variations suitable for harmonic analysis, the non-cyclic change has other than merely statistical significance. If, in the process of forming the hourly values of the elements from the magnetograms, all non-magnetic contributions to the recording of the elements (*e.g.* temperature effects and mechanical instrumental drift arising from subsidence of pillar supports) have been satisfactorily provided for in assigning base line values, the average daily non-cyclic change should be negligible, provided the secular change within the period is small. The annual and seasonal means of the non-cyclic change from *all* days (Table 19) show that these conditions are approximately met in all elements. In the separate months the change, though always small, is variable in sign and magnitude primarily because the effect of quiet or disturbed hours in raising or depressing the mean hourly values at either end is averaged over a shorter period. In declination, which Table 18 showed to be least affected by disturbance, the average aperiodic change on all days is greater than 0·3′ in only one month.

§ 36. *Non-cyclic change on quiet days.*—Monthly non-cyclic changes from the average of five selected quiet or disturbed days might be expected to be even more variable than for all days. Firstly, because they are determined by only ten hourly values at each end of the day, and, secondly, because few even of the international quiet days at Fort Rae were free of disturbance. It is therefore surprising to find twelve out of the thirteen quiet-day monthly values of the non-cyclic change in H of the same sign. In localities farther south from the auroral zone the non-cyclic change in H is almost invariably positive on the average of quiet days, and negative on disturbed days. These directions are generally interpreted as indicating that the horizontal component of the magnetic field during quiet conditions is building itself up from the depression created during the second phase of disturbance (*nachstörung*). But at Fort Rae, though the $q-d$ and $q-a$ values for H in Table 17 are consistently positive as for localities in lower latitudes, the non-cyclic change is preponderantly in the opposite direction and of substantial magnitude. It has been thought advisable to examine this seeming paradox in various ways.

TABLE 19.—NON-CYCLIC CHANGES APPLIED TO MONTHLY MEAN INEQUALITIES.

Month and Season.	All Days.			Quiet Days.			Disturbed Days.		
	H.	D.	Z.	H.	D.	Z.	H.	D.	Z.
	γ	′	γ	γ	′	γ	γ	′	γ
1932 Aug.	−0·1	+0·2	−0·4	−11·1	+0·3	−5·0	+18·6	+2·2	− 5·9
Sept.	+1·4	−0·1	+0·6	− 3·9	0·0	−1·3	+12·7	+1·7	− 9·7
Oct.	−1·3	+0·2	+0·2	− 8·1	−1·0	−2·1	− 1·1	+1·2	+ 4·2
Nov.	−0·2	0·0	−0·6	− 4·1	+1·4	−1·2	+12·8	−1·0	+ 1·5
Dec.	+1·9	−0·1	−0·1	− 2·5	0·0	−0·2	+ 6·4	0·0	+ 1·0
1933 Jan.	−1·6	0·0	+0·7	− 2·6	0·0	−1·0	+20·3	−1·9	− 1·8
Feb.	+0·2	−0·1	−0·1	− 3·2	+0·9	−1·6	+ 8·6	−1·9	−29·3
Mar.	0·0	+0·1	−0·3	− 5·0	+0·7	−4·6	+28·4	+0·6	−24·1
Apr.	+2·5	−0·6	−3·2	−18·7	+0·5	+3·3	+28·9	−0·4	− 3·5
May	−0·5	+0·3	+2·4	+ 4·4	−0·8	+1·9	−23·2	+1·0	+30·1
June	−1·1	+0·2	+0·2	− 9·5	+0·9	−7·5	−35·4	+2·2	+19·6
July	−1·0	−0·1	+0·1	− 7·0	−1·0	−5·1	−10·2	+1·7	− 3·0
Aug.	+0·6	0·0	+0·6	− 6·5	−0·3	+0·2	+16·5	+1·5	−11·1
y	$+0{\cdot}0_5$	0·0	0·0	− 5·7	+0·1	−1·8	+ 5·5	+0·4	− 2·0
w	+0·1	−0·1	0·0	− 3·1	+0·6	−1·0	+12·0	−1·2	− 7·1
e	+0·7	−0·1	−0·7	− 8·9	+0·1	−1·2	+17·2	+0·8	− 8·3
s	−0·6	+0·1	+0·7	− 5·2	−0·2	−3·3	−12·8	+1·7	+ 9·5

§ 37. *Examination of the negative non-cyclic change in H on* q *days.*—(i) An examination was first made of groups of consecutive quiet days on the ground that a possible explanation might be found in the relationships between the daily mean values on such days. Because positive values for $q-a$ and $q-d$ would not be inconsistent with negative values of the non-cyclic change if it could be shown that, on the average of two or more consecutive q days, the daily mean value tended to fall from the earlier to the later date. Using as a criterion a combination of $HR_H + ZR_Z$ and $Hr_H + Zr_Z$ (§§ 71 and 72) designed to select the least disturbed Greenwich days at Fort Rae independently of the international magnetic character figures, a list of sequences of such locally quiet days was prepared. In the 44 days in this list there was one sequence of 6 days, one of 5, three of 4, three of 3, and six of 2. The difference (which for every day was positive) between the mean value for each quiet day and the mean for all days of the month in which it occurred was tabulated (column 2 of Table 20). Examination was then made of the direction of change in the mean value of H for each one of the available pairs of consecutive days to the next. Of the 30 pairs, 15 showed an increase (average $+8{\cdot}7\,\gamma$) and 14 a decrease (average $-8{\cdot}9\,\gamma$), with one no change. The net change was therefore $+0{\cdot}8\,\gamma$ for the 30 pairs.

When a similar inquiry was made, using an extended list of sequences of slightly less quiet days, the results were:

Number of increases from one day to next of a pair, 21 (average rise $11{\cdot}4\,\gamma$);

Number of decreases from one day to next of a pair, 15 (average fall $12{\cdot}7\,\gamma$),

giving a net rise in 36 pairs of $1{\cdot}6\,\gamma$.

TABLE 20.—SEQUENCES OF LOCALLY QUIET DAYS AND THE EXCESS OF THEIR DAILY MEAN VALUE OF H OVER THE MONTH'S MEAN.

Date.	Excess over Monthly Mean.	Direction and Magnitude of Change.	Date.	Excess over Monthly Mean.	Direction and Magnitude of Change.
1932.	γ	γ	1933.	γ	γ
Aug. 16	43·9		Jan. 4	11·7	
17	29·0	−14·9	5	19·2	+ 7·5
18	32·8	+ 3·8	Feb. 10	42·5	
19	24·1	− 8·7	11	27·2	−15·3
Sept. 10	33·2		Mar. 6	17·4	
11	45·5	+12·3	7	21·8	+ 4·4
12	38·2	− 7·3	8	22·8	+ 1·0
16	34·6		9	34·0	+11·2
17	30·0	− 4·6	Apr. 12	27·4	
Oct. 6	36·2		13	13·1	−14·3
7	35·6	− 0·6	May 25	20·3	
8	35·6	0·0	26	9·6	−10·7
Nov. 7	10·1		27	22·9	+13·3
8	26·2	+16·1	June 22	26·6	
9	35·5	+ 9·3	23	16·4	−10·2
10	28·4	− 7·1	July 30	11·5	
11	20·4	− 8·0	31	25·1	+13·6
Dec. 2	24·5		Aug. 1	38·7	+13·6
3	28·4	+ 3·9	2	23·2	−15·5
			3	34·2	+11·0
			4	33·7	− 0·5
			10	22·3	
			11	24·0	+ 1·7
			12	24·2	+ 0·2
			13	2·1	−22·1

TABLE 21.—$\frac{1}{4}$-DAY MEAN VALUES OF H ON INTERNATIONAL q DAYS AND ON PRECEDING AND SUCCEEDING DAYS.

(Column headings are the hours G.M.T. defining the $\frac{1}{4}$-days, and entries are excesses of H value over 7700 γ.)

Month and Season.	Preceding Day.				Selected q Day.				Succeeding Day.			
	0–6h.	7–12h.	13–18h.	19–24h.	0–6h.	7–12h.	13–18h.	19–24h.	0–6h.	7–12h.	13–18h.	19–24h.
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
1932 Aug.	86·5	40·3	31·0	54·4	91·5	59·3	47·2	53·6	78·2	59·6	43·0	56·5
Sept.	63·1	33·0	7·2	53·7	71·6	50·1	34·8	51·1	76·8	38·0	18·3	38·7
Oct.	74·1	−10·6	−26·2	60·5	66·4	50·5	39·1	58·2	80·6	−22·6	−11·0	67·9
Nov.	79·8	26·3	25·1	56·2	75·3	37·5	49·1	56·7	67·4	34·0	19·2	57·1
Dec.	83·5	1·0	30·3	58·3	74·7	− 1·3	47·6	57·3	74·6	1·1	− 7·1	66·0
1933 Jan.	65·6	22·7	32·5	55·0	63·5	39·8	45·3	54·7	74·9	17·2	8·2	60·8
Feb.	84·9	11·1	19·3	61·3	66·3	49·2	43·2	56·3	61·0	3·1	37·9	60·3
Mar.	71·2	34·4	23·7	45·6	66·9	36·3	45·6	46·8	65·0	50·7	16·0	52·6
Apr.	65·2	14·5	28·2	59·5	96·6	28·6	45·2	55·2	83·1	27·1	33·2	53·4
May	84·2	27·0	21·4	156·3	78·6	27·6	53·7	51·8	86·8	10·5	37·7	59·1
June	104·8	41·1	41·7	56·6	102·2	36·3	52·3	53·7	− 9·2	44·4	16·2	67·3
July	113·3	46·3	34·0	63·2	96·4	30·7	53·5	58·0	97·4	47·7	49·7	63·0
Aug.	75·3	29·1	32·1	42·8	69·6	44·4	38·4	34·1	61·2	43·2	40·8	39·4
Mean Year	80·9	24·3	23·1	63·3	78·4	37·6	45·8	52·9	69·1	27·2	23·3	57·1
				70·8				61·0				
	47·9				53·7				44·2			

The evidence of the inquiry is therefore against the hypothesis of the mean daily value on the first of a set of consecutive quiet days being greater than that of succeeding days. From this result alone, the expectancy should be for a periodic effect small in size but positive in sign, and therefore opposed to the values actually obtained.

(ii) Another approach was made by examining whether the apparently anomalous direction of change might not arise from the use of pairs of hourly values on either side of midnight, instead of longer intervals in which effects of short period disturbance centred near midnight would be smoothed out. Mean values of H were therefore prepared, covering the four intervals of 6 hours, 0–6h, 7–12h, 13–18h, and 19–24h G.M.T. of each of the 65 internationally selected *q* days and for the single days immediately before and after these days.

The means from the five days per month of these $\frac{1}{4}$-day values on quiet and adjacent days are shown in Table 21 along with a comprehensive set of means from the 13 months together. These last show that

(1) The value of H for the last quarter of the Greenwich day before the selected *q* day exceeds by 10·4 γ the value for the last quarter of the quiet day itself.

(2) The value of H for the first quarter of the selected *q* day exceeds by 9·3 γ the value for the first quarter of the day following the quiet day. So that

(3) The half-day value centred at the first midnight of the selected *q* day exceeds the half-day value centred at the second midnight by 9·8 γ. This direction of change is true of nine of the thirteen separate months. And

(4) (Observable more simply otherwise) The mean value over the whole *q* day exceeds by 5·8 γ the value for the day before it, and by 9·5 γ the value of the day after it.

To see how far these conclusions might be affected by the onset of disturbance immediately after the average *q* days, those of the 65 international *q* days were selected, which were followed by *q* days, and the process described above was repeated. The average value over the six hours before and after the Greenwich midnights of the 21 days so found are as follows:—

	1st Midnight.		2nd Midnight.	
Mean value for hours ending	19h–24h	1h–6h	19h–24h	1h–6h
	7755·2	7781·3	7754·1	7778·2
	7768·3		7766·1	

The fall in H in the hours before and after the two midnights has now been diminished from 9·8 γ for all the 65 days to 2·2 γ for those *q* days which have another *q* day following them.

Now the results (1), (2), and (3) above make it clear that the negative non-cyclic change in *q* days is not confined to the two (Greenwich) midnight hours, but that, for a period of 12 hours centred at the two midnights defining the selected days, H is apparently higher at the beginning than at the end of the average *q* day. And taken with (4), we are led to picture the *q* days as lying mainly on the down-sloping sides of the crests of transitory waves of increase of horizontal force. In the more rigorous selection of *q* days, which were immediately followed by *q* days, risk of spurious effects, arising from the sudden onset of disturbance after quiet conditions, was further reduced, and the crest of quiet was broadened so that the decrease from the one midnight to the next was diminished. This result, by itself, however, throws little light on the phenomenon we are seeking to explain. For if purer quiet conditions decrease the negative aperiodic effect, it could be assumed that on wholly quiet days the sign would be positive. But the third section of Table 19 shows that the predominating sign for disturbed days is positive. Further insight is therefore sought by considering the nature of the non-cyclic change itself. Instead of assuming that the change throughout the hours between the midnights defining the day is proportional to the whole day change, let us form a fresh non-cyclic change by the process described at the beginning of § 35 for a set of days each retarded by one hour from the Greenwich day. This has been done, and the results for H are shown in Table 22, in which the entries in the first column are the mean non-cyclic changes for the international quiet days already used in forming Table 19, and the succeeding columns are the excesses similarly formed, of the second over the first midnight for days starting progressively one hour later than the Greenwich day, until in column 8 the day becomes coincident with the local zonal time day only 15 minutes behind the local mean time day.

TABLE 22.—NON-CYCLIC CHANGE OF H FOR GREENWICH DAYS AND FOR 8 DAYS STARTING PROGRESSIVELY ONE HOUR LATER.

Month.	Greenwich Day.	Days retarded by							Local Day.
		1h.	2h.	3h.	4h.	5h.	6h.	7h.	
	γ	γ	γ	γ	γ	γ	γ	γ	γ
1932 Aug. . .	−11·1	−28·2	−16·9	−12·4	− 9·4	−12·5	−12·6	− 3·7	+ 9·3
Sept. . .	− 3·9	+ 3·9	+ 7·3	+ 7·4	+ 9·8	+ 4·2	−10·6	−25·6	−28·7
Oct. . .	− 8·1	+ 1·0	+ 5·4	+ 2·2	+30·1	+39·2	+ 8·8	−15·5	−39·5
Nov. . .	− 4·1	− 7·9	− 7·6	− 4·2	− 5·5	−11·5	− 5·4	+14·5	+16·9
Dec. . .	− 2·5	+ 1·4	− 0·1	− 1·2	+ 6·1	− 1·2	− 8·9	−15·5	+ 0·7
1933 Jan. . .	− 2·6	− 2·4	+ 1·2	+13·6	+27·3	+17·1	+ 3·6	+ 7·3	+ 3·4
Feb. . .	− 3·2	− 1·8	− 2·1	− 1·0	− 0·4	− 3·0	−16·6	−25·5	−19·9
Mar. . .	− 5·0	− 5·6	− 4·4	− 1·8	0	+ 1·7	+ 7·4	+29·0	+31·0
Apr. . .	−18·7	−24·2	−22·2	−11·5	− 4·3	− 3·8	+ 3·2	+19·3	+24·2
May . .	+ 4·4	+18·1	+19·4	+15·0	− 0·1	− 8·5	− 1·4	−18·6	−28·4
June . .	− 9·5	−18·5	−24·1	−13·9	− 3·4	− 1·7	− 4·9	+ 4·1	+14·5
July . .	− 7·0	− 7·7	− 2·6	+ 1·9	+ 4·6	+ 9·8	+10·1	+ 0·6	− 5·6
Aug. . .	− 6·5	−14·1	− 8·7	− 8·0	−12·0	− 9·4	− 2·6	− 0·1	+ 0·8
Mean . . .	− 5·7	− 6·6	− 4·3	− 1·1	+ 3·3	+ 1·6	+ 2·3	− 2·3	− 1·6
Average Departure .	3·8	9·4	9·1	7·0	9·5	10·0	7·9	13·9	17·5

Taking the 13 months together, the mean non-cyclic changes show that both the direction and magnitude of the change vary considerably with the epoch from which the day is defined. Had any other epoch but Greenwich midnight or 1.0 a.m. G.M.T. been used in starting the day, the average non-cyclic change would have been substantially less than it indeed is, and for three of the days beginning 4h, 5h, and 6h G.M.T. it would actually have been positive over the average of all *q* days. It must therefore be inferred that the negative value for the H non-cyclic change on *q* days, shown in Table 19, is largely accidental.

Except for some few very specialised phenomena, such as the incidence of sudden commencements, Greenwich or universal time bears no relation to magnetic events at Fort Rae; local time is the dominating influence in the regular diurnal variations and in irregular disturbance. It is true that the use of the local day in forming even the quiet-day variations would have given no clearer picture of the average non-cyclic change on quiet days. For the last line of Table 22, showing the mean departures of the separate monthly values of non-cyclic change from the year's mean, indicates that the variations about this mean are enormously greater for the local day than any of the other nine days examined. This is a natural corollary of the phase of the diurnal variation of irregular disturbance, for, as will be shown in §§ 82–83, disturbance at Fort Rae on quiet as well as on disturbed days has a pronounced and sharp maximum at local midnight, so that variability in the non-cyclic change determined by hourly values drawn from that time of day is most to be expected then.

This last point is clearly emphasised by determining, in a precisely similar way to that for all q days, the average non-cyclic change for periods of 24 hours progressively delayed by one hour from Greenwich to local midnight for the 21 international quiet days which were themselves followed by quiet days. The results are shown in Table 23.

TABLE 23.—NON-CYCLIC CHANGE OF H FOR q DAYS EACH FOLLOWED BY q DAYS DEFINED BY GREENWICH TIME AND DAYS STARTING ONE HOUR LATER.

	Hours later than Greenwich Day.							Local Day.
.	1.	2.	3.	4.	5.	6.	7.	8.
n.c. change (γ) . .	−11·2	−8·4	−2·3	+2·5	+2·8	+2·1	+9·8	−0·2

In this selection the chance of the second midnight value being disturbed is reduced compared with the chance when 65 q days are used. And yet within the eight hours before local midnight the non-cyclic change on these protected q days can vary from $-11{\cdot}2\,\gamma$ to $+9{\cdot}8\,\gamma$. The change becomes almost systematically more positive up to the day beginning one hour before local midnight, but for the local midnight itself it abruptly changes by $10\,\gamma$. This is attributable to no other influence than short period irregular disturbance concentrated in the hours of this time of day.

All that has been said relates to horizontal force, but so far as the phenomena are influenced by local disturbance, similar conclusions would also hold for D and Z, in which elements the magnitude of the changes are smaller than in H.

§ 38. *Non-cyclic change on disturbed days.*—If disturbance plays such a large part in determining the non-cyclic change in quiet days, its influence on days selected because they are disturbed must be overwhelming. This is again most easily demonstrated by comparing the separate monthly values of the change in the column H under disturbed days in Table 19 with the year's mean of $+5{\cdot}5\,\gamma$. Between April and June the monthly values change from $23\,\gamma$ above to $41\,\gamma$ below the mean. It is therefore very uncertain whether disturbed day non-cyclic changes have even as much physical significance as those for q days. In H, it is true, the separate values are positive in nine of the thirteen months, and, what is more surprising, in ten months the signs of the q and d non-cyclic changes are in opposite directions. This is probably the strongest justification for assuming that at least on the Greenwich days H tends to fall on quiet days and rise on disturbed days. But, as has been shown in the examination of q day non-cyclic changes, it is probable that if the wholly accidental effects of irregular disturbance could be eliminated and true local days used, opposite tendencies would be found. Certainly the reversals in sign for both H and Z in summer d days as compared with the winter and equinox seasons are entirely fortuitous.

The uncertainties attaching to the interpretation of non-cyclic changes are further illustrated by Table 24, which gives the values of the change for the limited number of Greenwich days selected as the 38 quietest and 40 most disturbed during the 13 months. Comparing the annual (y) means in this table with those for the ordinary q and d days of Table 19, it is seen that only in D for disturbed days is the sign of the change the same. In view of the discussion in foregoing paragraphs, the values for H are particularly interesting. They show that on the quietest days the non-cyclic change in these elements may indeed be positive except in the most disturbed equinox season, and except in the same season the tendency is for the non-cyclic change to be negative in the most disturbed days. These directions of change from the first to the second midnight are both consistent with the effects of disturbance on the mean value of H discussed in § 34.

TABLE 24.—NON-CYCLIC CHANGES ON QUIETEST (q') AND MOST DISTURBED (d') DAYS.

Season.	H.		D.		Z.	
	q'.	d'.	q'.	d'.	q'.	d'.
	γ	γ	′	′	γ	γ
y	+ 6·8	−10	−0·4	+3·2	+1·0	+ 4
w	+ 1·0	−12	−0·2	+0·7	−1·9	−16
e	− 3·3	+ 2	−0·4	+0·2	−1·4	+28
s	+22·7	−19	−0·6	+8·6	+6·4	0

§ 39. *Overlapping day means.*—Primarily in conformity with an international recommendation, daily means have been constructed for the 24-hourly periods centred at 0h, 6h, and 18h G.M.T. each day, as well as for the usual period centred at 12h. This was done for all days of the 13 months and for each of the three components separately. The formation of these overlapping 24-hourly mean values, centred at successive 6-hour intervals, allows the general day-to-day march of the elements to be studied unhampered by the interdiurnal regular variations or by the short period characteristics of disturbance. The results are not given in arithmetical form, but, as departures from the all-day means of each month, they are reproduced graphically in fig. 3. The vertical scales for the three components in these figures are such that in terms of the force equivalent perpendicular to the meridian, the scale for declination is approximately the same as for the true force components H and Z.

While details of these figures can be considered only in relation to corresponding day-to-day changes at other stations, several broad features of prominence stand out from the march of events at Fort Rae alone.

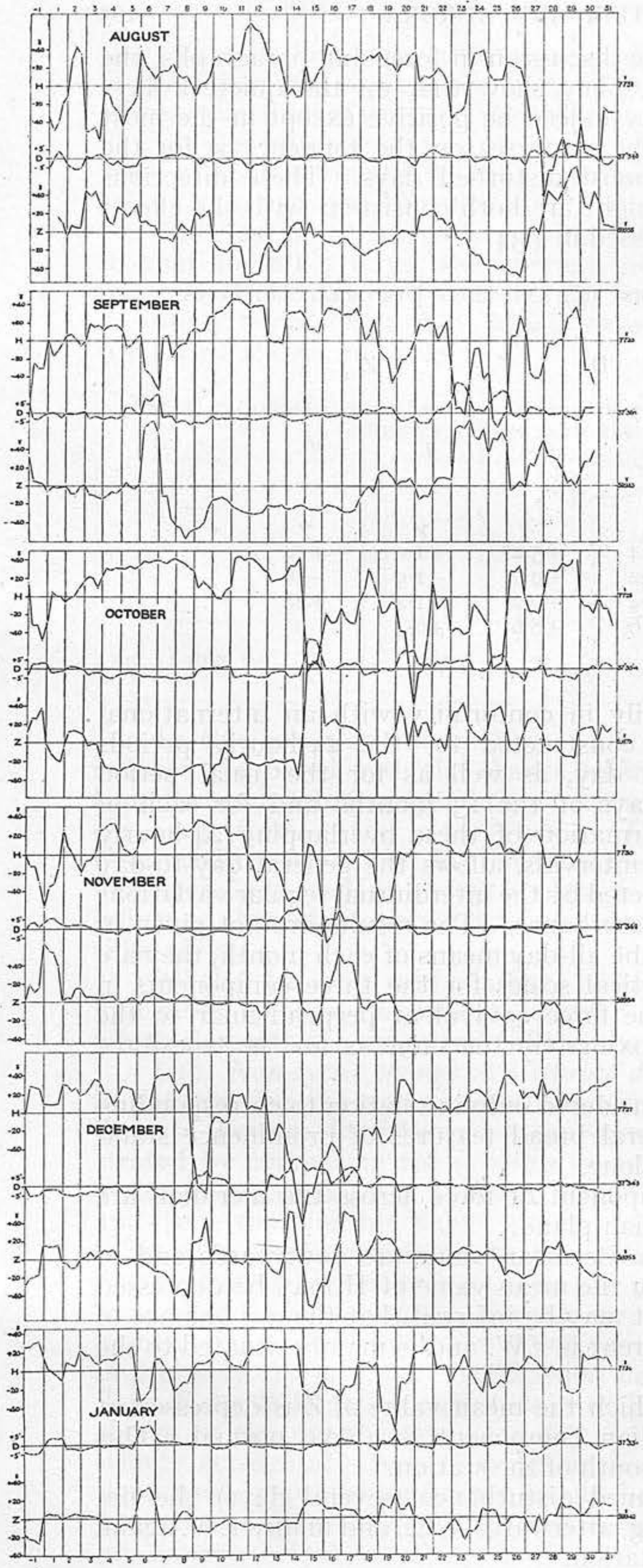
(i) The changes in the horizontal component of force across the meridian are always small, relative to those in the meridian plane.

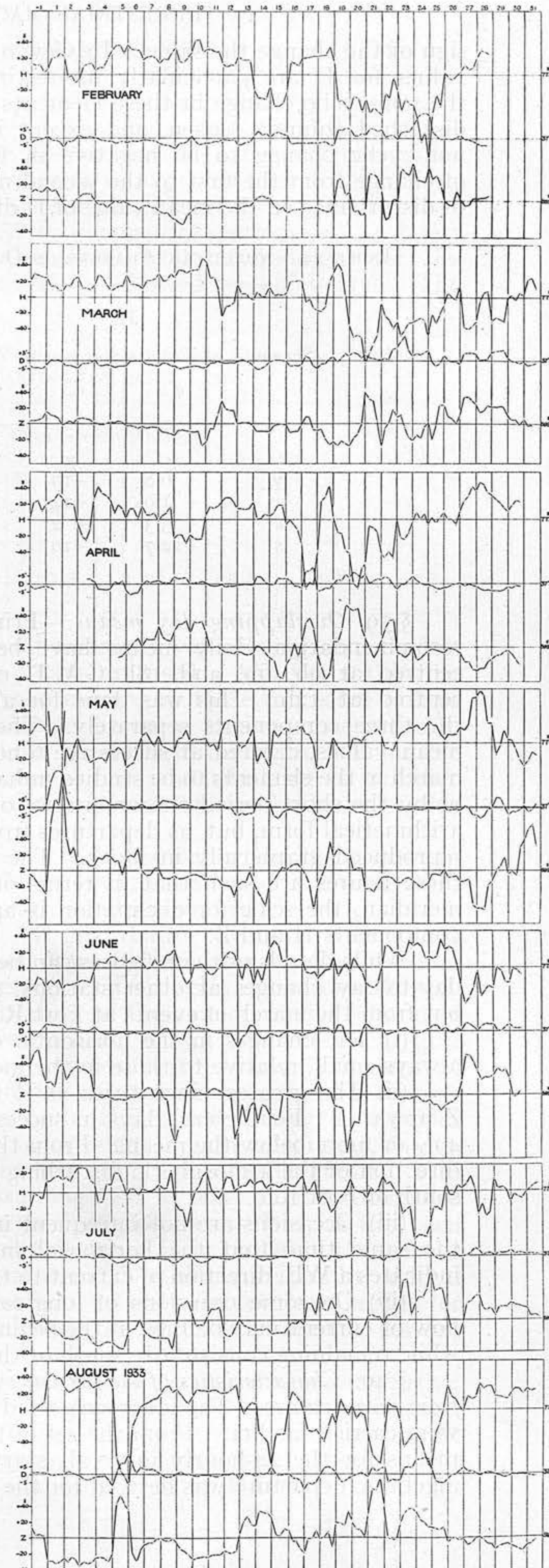
(ii) The greatest departures of H from its mean value are downwards and of Z upwards. For several days in succession the mean value of H may be depressed 40 γ or more below the mean. From this it may be inferred that the net balance of direction of the atmospheric disturbing current is EW. and is mainly situated to the south of Fort Rae.

(iii) Occasions are not infrequent in which the mean value of Z is depressed at the same time that the horizontal meridian component is above normal. This indicates a WE. direction of current to the south of the station.

(iv) On some occasions of long-continued disturbance (several days) the net flow of current may be EW. at the beginning, afterwards WE., and finally EW. again, while remaining consistently south of the station.

§ 40. *Characteristics of the current system necessary to produce H and Z departures from mean values.*—The ideas suggested by the graphs of the overlapping day means were carried farther. From the set of four departures from the all-day mean of the means for the 24-hourly intervals starting 0h, 6h, 12h, and 18h each day a total algebraic departure was derived for the force components H and Z. Denoting these





Note.—In each month's compartment the upper line represents the trend of H, the middle (more regular) line D, and the lowest line Z. The scale for D, in terms of equivalent force across the meridian, is chosen to be about the same as for H and Z.

FIG. 3.—Day-to-day trend of elements throughout 13 months.

total departures by ΔH and ΔZ, values of the ratio ΔH/ΔZ were determined for each day. To illustrate by an example: on 1932 August 2 the difference between the mean value of H for the day centred at 0h. and the all-day mean for August was

TABLE 25.—POSITIONS OF CURRENT SYSTEM ON q' AND d' DAYS DEDUCED FROM OVERLAPPING DAILY MEANS OF H AND Z.

38 Quietest Days.					40 Most Disturbed Days.				
Date.	Col. A.		Col. B.		Date.	Col. A′.		Col. B′.	
	E.	D.	E.	D.		E.	D.	E.	D.
1932 Aug. 11	S. 58°	WE.	S. 63°	WE.	1933 Aug. 3	S. 52°	EW.	S. 46°	EW.
19	S. 64	WE.	S. 63	WE.	27	N. 80	EW.	S. 83	EW.
24	S. 48	WE.	S. 53	WE.	28	S. 71	EW.	S. 68	EW.
Sept. 12	S. 51	WE.	S. 52	WE.	29	S. 51	EW.	S. 50	EW.
16	S. 54	WE.	S. 57	WE.	30	S. 62	EW.	S. 72	EW.
Oct. 6	S. 54	WE.	S. 54	WE.	Sept. 20	S. 78	EW.	S. 76	EW.
7	S. 51	WE.	S. 48	WE.	23	S. 53	EW.	S. 48	EW.
12	S. 59	WE.	S. 57	WE.	24	S. 24	EW.	S. 9	EW.
14	S. 55	WE.	S. 61	WE.	25	S. 57	EW.	S. 62	EW.
Nov. 7	N. 72	WE.	N. 75	WE.	27	S. 52	EW.	S. 61	EW.
10	S. 85	WE.	S. 84	WE.	Oct. 15	S. 44	EW.	S. 41	EW.
24	S. 63	WE.	S. 64	WE.	21	S. 77	EW.	S. 76	EW.
27	S. 52	WE.	S. 53	WE.	Nov. 16	S. 77	EW.	S. 77	EW.
Dec. 7	S. 68	WE.	S. 68	WE.	Dec. 9	S. 71	EW.	S. 75	EW.
1933 Jan. 4	S. 69	WE.	S. 67	WE.	14	S. 65	EW.	S. 54	EW.
5	S. 68	WE.	S. 72	WE.	15	N. 68	EW.	N. 57	EW.
10	S. 66	WE.	S. 72	WE.	1933 Feb. 21	S. 63	EW.	S. 50	EW.
12	S. 67	WE.	S. 69	WE.	22	N. 76	EW.	N. 57	EW.
21	S. 85	WE.	S. 90	WE.	23	S. 50	EW.	S. 41	EW.
Feb. 6	S. 78	WE.	S. 77	WE.	24	S. 63	EW.	S. 73	EW.
11	S. 73	WE.	S. 74	WE.	25	S. 60	EW.	S. 37	EW.
13	S. 69	WE.	S. 72	WE.	Mar. 20	N. 71	EW.	N. 74	EW.
17	S. 67	WE.	S. 68	WE.	21	S. 68	EW.	S. 64	EW.
Mar. 7	S. 76	WE.	S. 77	WE.	22	N. 81	EW.	S. 88	EW.
8	S. 69	WE.	S. 64	WE.	23	N. 89	EW.	N. 83	EW.
9	S. 72	WE.	S. 77	WE.	24	N. 64	EW.	N. 56	EW.
Apr. 12	S. 77	WE.	S. 78	WE.	25	S. 89	EW.	N. 85	EW.
May 12	S. 46	WE.	S. 54	WE.	Apr. 17	S. 71	EW.	S. 65	EW.
26	S. 59	WE.	S. 51	WE.	19	S. 38	EW.	S. 39	EW.
June 23	S. 74	WE.	S. 73	WE.	20	S. 58	EW.	S. 60	EW.
July 13	S. 55	WE.	S. 41	WE.	21	N. 85	EW.	N. 36	EW.
Aug. 1	S. 54	WE.	S. 51	WE.	22	S. 61	EW.	S. 50	EW.
4	S. 52	WE.	S. 54	WE.	May 1	S. 35	EW.	S. 28	EW.
10	S. 41	WE.	S. 44	WE.	6	S. 48	EW.	S. 56	EW.
11	S. 46	WE.	S. 49	WE.	18	S. 83	EW.	S. 80	EW.
12	S. 54	WE.	S. 53	WE.	June 13	N. 3	EW.	S. 8	WE.
28	S. 81	WE.	S. 75	WE.	14	N. 30	EW.	N. 56	EW.
31	S. 74	WE.	S. 81	WE.	July 24	S. 64	EW.	S. 64	EW.
					Aug. 5	S. 58	EW.	S. 55	EW.
					21	S. 44	EW.	S. 46	EW.
Mean	S. 64	WE.	S. 65	WE.	Mean	S. 73	EW.	S. 68	EW.

$-10\,\gamma$; for Z the corresponding difference was $-3\,\gamma$. In the same way, for the 24-hour periods centred at 6h, 12h, and 18h the differences were $+28\,\gamma$, $+43\,\gamma$, and $+35\,\gamma$ for H, and $+7\,\gamma$, $+5\,\gamma$, and $+5\,\gamma$ for Z. These gave a total departure of $+96\,\gamma$ for

H and $+14\gamma$ for Z, the ratio $\Delta H/\Delta Z$ being 6·86. If these departures of the components of force from average conditions can be regarded as due to the effect of a current system situated above the earth's surface, then the elevation of the system, supposed concentrated, is $\tan^{-1} 6{\cdot}86$ or 82° above the N. horizon in the magnetic meridian, and the direction of the current necessary to produce these departures of positive sign in both H and Z is from W. to E.

This determination of elevation and direction was made for all days of complete H and Z record in the 13 months. The numerical results are not given, but are graphically represented in fig. 4. In this figure the central line for each month represents an overhead position of the current, distance above or below that line indicates the angular zenith distance of the current to magnetic north and south of the station. A × implies a WE. current direction; a · an EW. direction. The internationally disturbed days have the × or · inset in a square and internationally quiet days in a circle.

Fig. 4 makes it clear that the direction of flow of current is predominantly WE. on quiet days and EW. on disturbed days. Of the 65 international quiet days within the period covered by fig. 4 the directions of the departures ΔH and ΔZ were such as to point to a WE. current direction to north or south of Fort Rae on 62 days, and out of the 65 disturbed days the balance of current flow was in the opposite direction on 51 days.

This distinction is emphasised by the contents of columns A and A′ of Table 25, which give the altitude angles (E) above the N. or S. horizon and direction (D) for the two groups of days described elsewhere in this discussion as *q′* and *d′* days. Without exception the direction is WE. on all of the 38 *q′* days and EW. on all of the 40 *d′* days. The average elevations are 64° above the S. (magnetic) horizon on *q′* days and 73° above the same horizon on *d′* days.

Columns B and B′ of the same table show that substantially similar results are obtained when, instead of the composite overlapping mean day, the simple daily means centred at 12h are used, the departures still being taken relative to the all-day monthly means. In both lists of days the current directions are with one exception (1933 June 13) as before, the mean altitudes being only slightly changed to 65° for *q′* and 69° for *d′* days.

It is of interest to note the systematic seasonal trend in the altitude angles on the quietest days and, to a less extent, on the most disturbed days. The former is apparent from fig. 5, which represents, in a similar way to that used in fig. 4 for all days, the contents of columns A and A′ of Table 25. In numerical form the seasonal mean altitudes above the magnetic south horizon, obtained by grouping the days in the two sets of columns of this table, are given in Table 26. June 13, the day of apparent

TABLE 26.—SEASONAL MEAN VALUES OF CURRENT ELEVATION ON *q′* AND *d′* DAYS.

Season.	38 Quietest Days.		40 Most Disturbed Days.	
	A.	A′.	B.	B′.
	°	°	°	°
w	73	74	74	73
e	62	63	71	73
s	58	58	64	58

WE. current in column B′, has been omitted from the *s* days in columns B and B′ In addition to the steady fall in altitude from *w* to *s* on *q′* days and, less regularly, on *d′* days, a noteworthy feature of this table is the similarity of the altitude angles obtained for the two contrasting classes of days. This result, as indeed also the

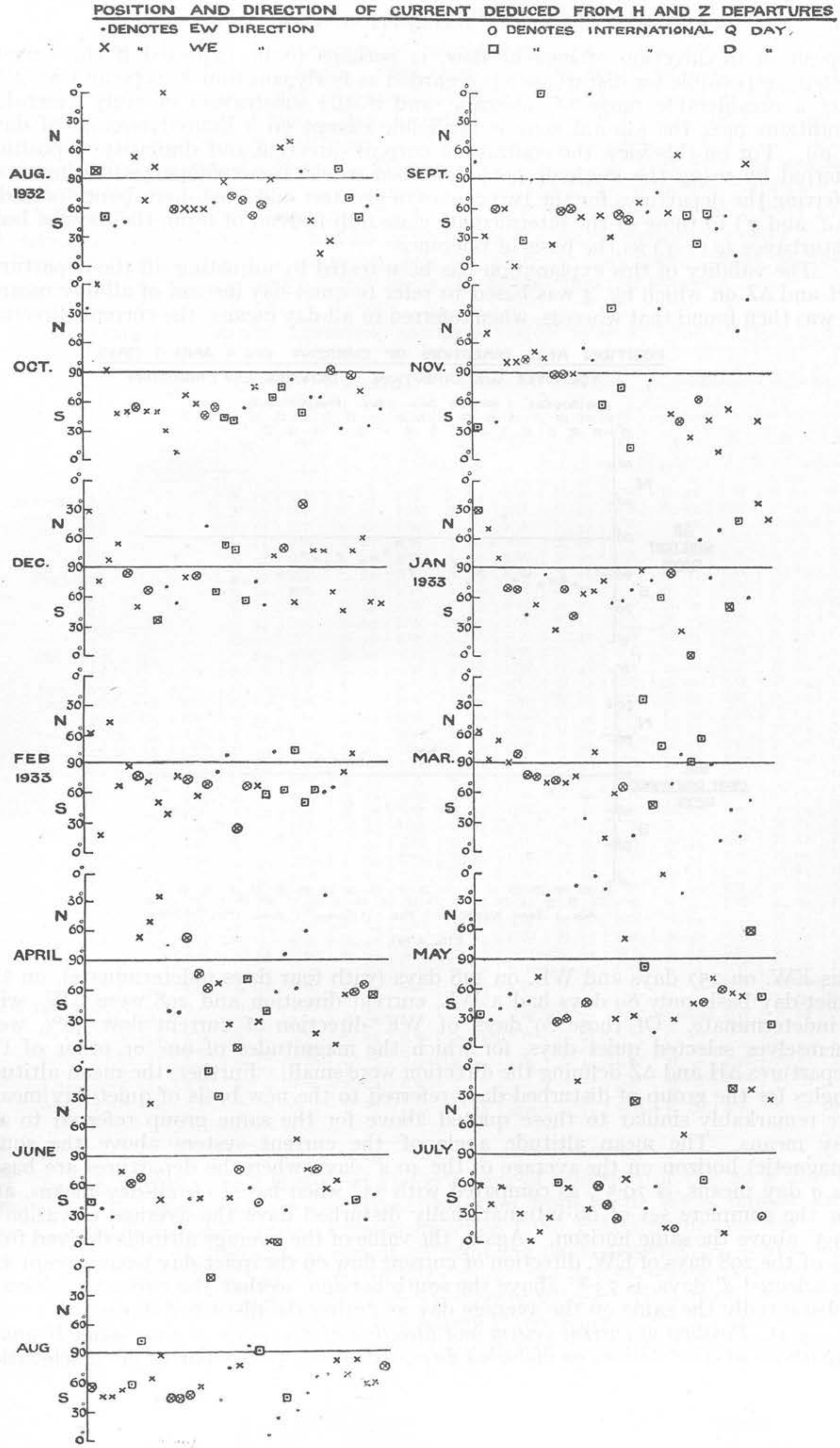

POSITION AND DIRECTION OF CURRENT DEDUCED FROM H AND Z DEPARTURES
• DENOTES EW DIRECTION
X " WE "
O DENOTES INTERNATIONAL Q DAY.
□ " " D "
AUG. 1932
SEPT.
OCT.
NOV.
DEC.
JAN 1933
FEB 1933
MAR.
APRIL
MAY
JUNE
JULY
AUG
N
S

FIG. 4.

opposition in direction of current flow, is perhaps to be expected if the current system responsible for disturbance is regarded as fairly constant in type and position over a considerable range of intensity, and if the substratum of truly quiet-day conditions near the auroral zone is negligible except on a limited number of days (§ 46). For on this view the contrast of current direction and similarity of position inferred by using the methods here described would be explained as arising from referring the departures for the two classes of greatest and least disturbance (d and q or d' and q') to those of the intermediate class (all) instead of using the days of least disturbance (q or q') as the basis of reference.

The validity of this explanation has been tested by adjusting all the departures ΔH and ΔZ on which fig. 4 was based to refer to quiet-day instead of all-day means. It was then found that whereas, when referred to all-day means, the current direction

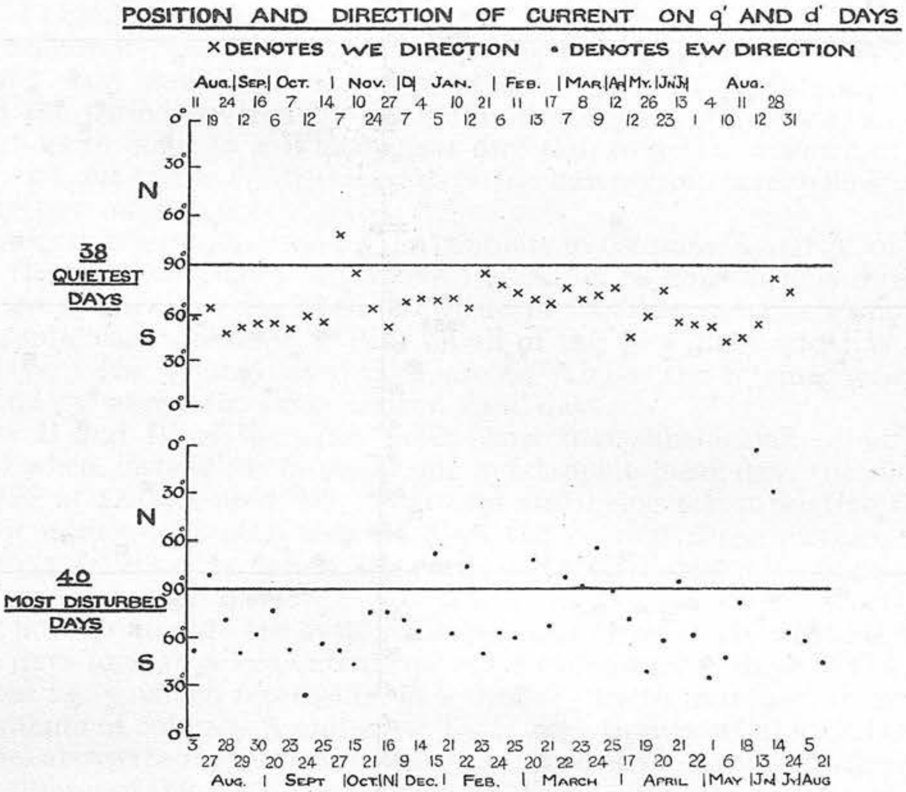


FIG. 5 (*a*).

was EW. on 157 days and WE. on 228 days (with four days indeterminate), on the quiet-day basis only 89 days had a WE. current direction and 298 were EW., with 2 indeterminate. Of those 89 days of WE. direction of current flow 30% were themselves selected quiet days, for which the magnitudes of one or other of the departures ΔH and ΔZ defining the direction were small. Further, the mean altitude angles for the group of disturbed days referred to the new basis of quiet-day means are remarkably similar to those quoted above for the same group referred to all-day means. The mean altitude angle of the current system above the south (magnetic) horizon on the average of the 40 d' days, when the departures are based on q day means, is 70·5°, as compared with 73° when based on all-day means, and for the complete set of 60 internationally disturbed days the average elevation is 73·5° above the same horizon. Again, the value of the average altitude derived from all of the 298 days of EW. direction of current flow on the quiet-day basis, except the 40 selected d' days, is 73·8° above the south horizon, so that the current position is substantially the same on the average day as during the disturbed days.

§ 41. *Position of current system and direction of flow deduced from mean H and Z departures at other stations on disturbed days.*—Utilising the similarity of the elevation angles whether derived from simple or overlapping means, the inquiry has been extended to six other observatories. The results for the set of 40 d' days are given in Table 27, and represented diagrammatically in fig. 5 (*b*). To obtain these, departures ΔH and ΔZ of the d' days centred at 12h G.M.T. have been measured from quiet-day means; for all observatories except Fort Rae and Tromsö these are the monthly means for the international quiet days; for Fort Rae the seasonal means of the 38 q' days were used, and at Tromsö the QM day means published by that observatory. The Godhavn data have kindly been supplied by Dr la Cour in advance of publication; blanks or bracketed entries under Scoresby Sound indicate that either the data are incomplete for whole or part days or that no quiet-day mean is available, in which latter event the all-day mean was used.

TABLE 27.—POSITION, ELEVATION, AND DIRECTION OF CURRENT ON d' DAYS.

Date.	Scoresby Sound.		Godhavn.		Fort Rae.		Tromsö.		Lerwick.		Eskdalemuir.		Rude Skov.	
	E.	D.	E.	D.	E.	D.	E.	D.	E.	D.	E.	D.	E.	D.
	°		°		°		°		°		°		°	
1932 Aug. 3	..	..	N. 13	WE.	S. 58	EW.	S. 84	EW.	N. 56	EW.	S. 32	EW.	S. 82	EW.
27	..	..	N. 26	WE.	S. 82	EW.	N. 83	EW.	S. 45	WE.	N. 11	EW.	S. 45	EW.
28	..	..	S. 23	EW.	S. 71	EW.	S. 77	EW.	N. 57	EW.	N. 48	EW.	Overhead	EW.
29	..	..	S. 11	EW.	S. 57	EW.	S. 62	EW.	S. 82	EW.	N. 80	EW.	S. 63	EW.
30	..	..	N. 13	WE.	S. 75	EW.	S. 73	EW.	N. 59	EW.	N. 57	EW.	S. 66	EW.
Sept. 20	..	..	N. 9	WE.	S. 80	EW.	N. 89	EW.	N. 21	EW.	N. 34	EW.	N. 83	EW.
23	..	..	S. 39	EW.	S. 57	EW.	S. 76	EW.	N. 22	EW.	S. 77	EW.	S. 71	EW.
24	..	..	S. 35	EW.	S. 39	EW.	S. 56	EW.	N. 25	EW.	N. 73	EW.	S. 86	EW.
25	..	..	S. 44	EW.	S. 67	EW.	N. 81	EW.	N. 31	EW.	N. 73	EW.	S. 80	EW.
27	..	..	N. 35	WE.	S. 70	EW.	N. 70	EW.	N. 40	EW.	N. 63	EW.	S. 77	EW.
Oct. 15	..	..	S. 75	EW.	S. 42	EW.	N. 19	EW.	N. 7	WE.	S. 41	EW.	S. 55	EW.
21	..	..	S. 16	EW.	S. 65	EW.	N. 88	EW.	N. 44	EW.	N. 68	EW.	N. 85	EW.
Nov. 16	..	..	S. 32	EW.	S. 71	EW.	N. 64	EW.	N. 54	EW.	S. 86	EW.	N. 76	EW.
Dec. 9	S. 86	EW.	S. 60	EW.	S. 73	EW.	N. 82	EW.	N. 60	EW.	S. 81	EW.	N. 86	EW.
14	S. 83	EW.	S. 88	EW.	S. 57	EW.	S. 89	EW.	S. 2	EW.	S. 50	EW.	S. 63	EW.
15	S. 54	EW.	S. 21	EW.	N. 69	EW.	N. 80	EW.	N. 52	EW.	N. 85	EW.	N. 83	EW.
1933 Feb. 21	S. 70	EW.	S. 49	EW.	S. 59	EW.	N. 45	EW.	N. 30	EW.	N. 78	EW.	S. 86	EW.
22	S. (79)	EW.	S. 58	EW.	N. 75	EW.	N. 81	EW.	N. 43	EW.	N. 52	EW.	N. 74	EW.
23	N. (54)	EW.	S. 62	EW.	S. 53	EW.	N. 61	EW.	N. 82	EW.	S. 72	EW.	S. 68	EW.
24	N. 86	EW.	S. 55	EW.	S. 74	EW.	N. 46	EW.	N. 84	EW.	S. 76	EW.	S. 68	EW.
25	S. 52	EW.	S. 58	EW.	S. 52	EW.	S. 68	EW.	N. 41	EW.	N. 77	EW.	S. 74	EW.
Mar. 20	S. (38)	EW.	S. 41	EW.	N. 86	EW.	S. 85	EW.	N. 51	EW.	N. 50	EW.	N. 72	EW.
21	S. 38	EW.	S. 33	EW.	S. 67	EW.	N. 83	EW.	N. 61	EW.	N. 54	EW.	N. 81	EW.
22	S. (55)	EW.	S. 32	EW.	S. 80	EW.	N. 80	EW.	N. 29	EW.	N. 31	EW.	N. 62	EW.
23	S. 62	EW.	S. 48	EW.	S. 87	EW.	N. 69	EW.	N. 24	EW.	N. 35	EW.	N. 81	EW.
24	S. (22)	EW.	S. 45	EW.	N. 81	EW.	N. 77	EW.	N. 36	EW.	N. 50	EW.	N. 83	EW.
25	S. (3)	EW.	S. 32	EW.	S. 85	EW.	S. 82	EW.	N. 49	EW.	N. 60	EW.	S. 84	EW.
Apr. 17	S. (45)	EW.	S. 52	EW.	S. 62	EW.	N. 82	EW.	N. 28	EW.	N. 81	EW.	N. 85	EW.
19	S. (10)	EW.	S. 55	EW.	S. 46	EW.	S. 75	EW.	N. 19	EW.	N. 49	EW.	N. 77	EW.
20	N. (1)	WE.	S. 86	EW.	S. 59	EW.	S. 0	EW.	S. 63	WE.	S. 60	EW.	S. 58	EW.
21	S. 21	EW.	S. 28	EW.	S. 82	EW.	S. 78	EW.	N. 65	EW.	S. 81	EW.	S. 76	EW.
22	S. (40)	EW.	S. 48	EW.	S. 51	EW.	N. 74	EW.	N. 16	EW.	N. 69	EW.	Overhead	EW.
May 1	N. 32	EW.	N. 87	EW.	S. 38	EW.	S. 34	EW.	S. 4	EW.	S. 10	EW.	S. 60	EW.
6	S. 67	EW.	S. 75	EW.	S. 70	EW.	S. 76	EW.	N. 51	EW.	Overhead	EW.	N. 61	EW.
18	S. (34)	EW.	S. 41	EW.	S. 83	EW.	S. 84	EW.	N. 52	EW	N. 56	EW.	N. 75	EW.
June 13	S. 11	EW.	N. 63	EW.	N. 15	EW.	..	..	N. 29	EW.	N. 18	EW.	N. 22	EW.
14	S. 23	EW.	S. 75	EW.	N. 79	EW.	N. 81	EW.	N. 39	EW.	N. 56	EW.	N. 77	EW.
July 24	S. 25	EW.	S. 0	EW.	S. 63	EW.	..	..	N. 30	EW.	N. 85	EW.	S. 85	EW.
Aug. 5	N. (42)	EW.	S. 79	EW.	S. 52	EW.	S. 79	WE.	N. 48	WE.	N. 35	WE.	N. 9	WE.
21	..	..	N. 45	WE.	S. 46	EW.	S. 68	WE.	N. 23	WE.	S. 69	EW.	S. 56	EW.

In spite of the local nature of the criterion of selection of the 40 d' days in Table 27, the predominance of current direction from E. to W. is unmistakable. At Fort Rae all 40 days have a current direction EW., Eskdalemuir and Rude Skov each have 39 days, Tromsö 36 out of 38 complete days, Lerwick 35, Godhavn 34, and Scoresby Sound 25 out of 26 complete days; the day of WE. current direction for this last station is a day of incomplete hourly values. It is worth notice that the only days of net WE. flow at Eskdalemuir and Rude Skov are the same day (1933 August 5), and that this day is one of the only two days with the same direction

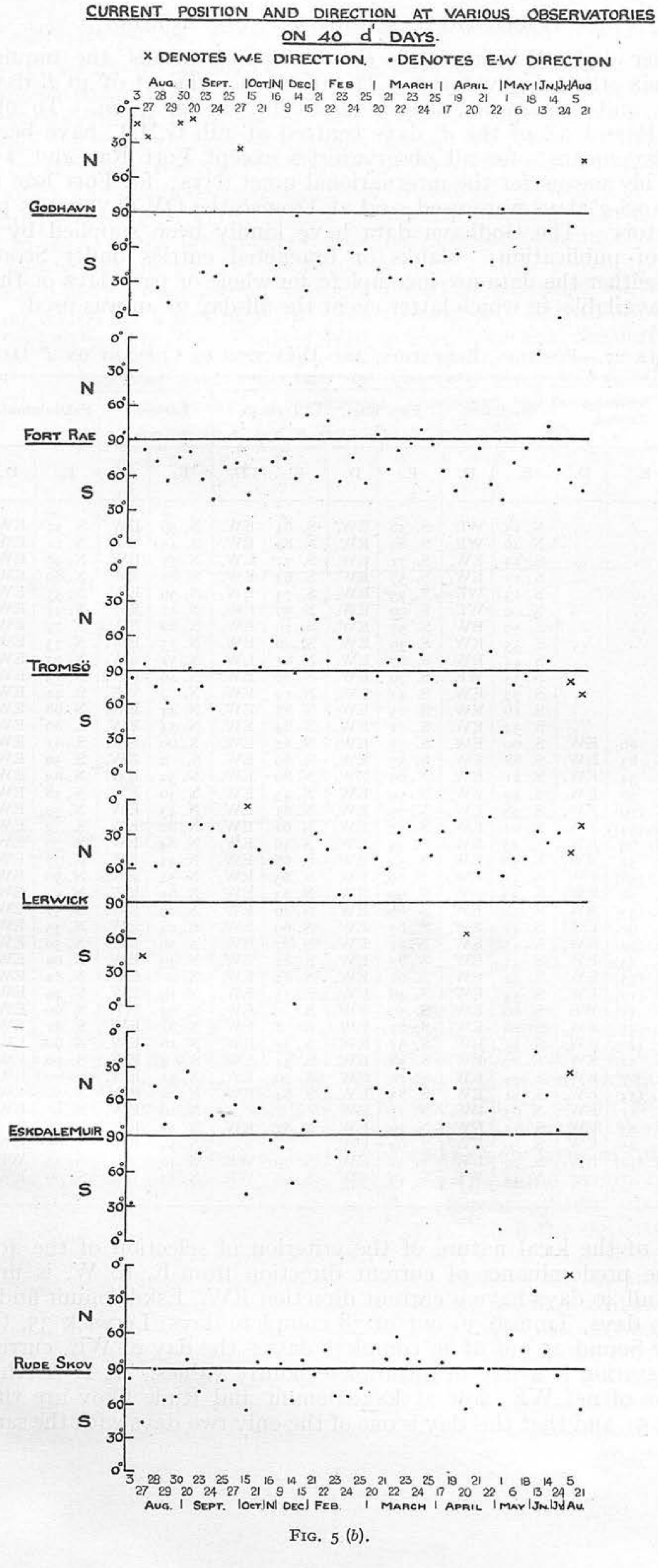

CURRENT POSITION AND DIRECTION AT VARIOUS OBSERVATORIES ON 40 d' DAYS.
× DENOTES W-E DIRECTION. • DENOTES E-W DIRECTION
Aug. | Sept. | Oct | N | Dec | Feb | March | April | May | Jn. | Jy. | Aug
3 28 30 23 25 15 16 14 21 23 25 21 23 25 19 21 1 18 14 5
27 29 20 24 27 21 9 15 22 24 20 22 24 17 20 22 6 13 24 21
Godhavn
Fort Rae
Tromsö
Lerwick
Eskdalemuir
Rude Skov
N
S
0°
30°
60°
90°

Fig. 5 (b).

at Tromsö and one of the five days at Lerwick. Further, the other day of WE. flow at Tromsö is one of the other remaining days of similar direction at Lerwick. At this last observatory the other three days have the smallest values of ΔH ($\leqslant 3\gamma$), so that little reliance can be put on the value of its sign and therefore on the direction of the current.

From the complete list of 40 d' days those seven days were discarded which were either lacking data or on which the current direction was WE. at one of the five stations, Fort Rae, Tromsö, Lerwick, Eskdalemuir, and Rude Skov. The mean altitudes for the 33 remaining common days, on all of which the direction was EW. at those five stations, are as follows:—

Fort Rae . .	70·9°	above S. horizon.
Tromsö . .	88·9	,, N. ,,
Lerwick . .	53·7	,, N. ,,
Eskdalemuir . .	76·5	,, N. ,,
Rude Skov . .	91·4	,, N. ,,

The inclusion of Godhavn in this group would have entailed the elimination of four additional days, since occasions of WE. current there did not coincide with those which had to be omitted for the other five observatories.

Using these mean altitudes, lines were drawn from points on a line curved to represent a magnetic meridian on which all five stations were supposed concentrated at distances proportional to the differences of their magnetic latitude. The altitude lines from Fort Rae, Tromsö, and Lerwick converged in a region approximately overhead at Tromsö and 700–800 km. above it, but the corresponding lines for Eskdalemuir and Rude Skov were neither consistent with this current situation nor with each other.

Out of the 33 d' days of net EW. current at these five observatories, 4 had WE. current predominating at Godhavn, 10·5° higher in magnetic latitude than Fort Rae, and unfortunately only 14 days out of the 26 available days at Scoresby Sound had the data complete in all respects. Hence, omitting Scoresby Sound, 29 days of uniformly EW. current at six stations are available for subdivision into seasons. These 29 days are distributed among the seasons as follows: 6 in summer, 9 in winter, and 14 in equinoctial months. Table 28 shows the mean altitude angles derived from the $\Delta H/\Delta Z$ ratio in the three seasons.

TABLE 28.—SEASONAL MEAN ELEVATIONS OF CURRENT SYSTEM REFERRED TO SIX STATIONS.

Season.	Godhavn.	Fort Rae.	Tromsö.	Lerwick.	Eskdalemuir.	Rude Skov.
	Magnetic Horizon.					
	S.	S.	N.	N.	N.	N.
	°	°	°	°	°	°
w	54	73	74	69	92	96
e	39	70	90	36	64	87
s	53	70	108	79	83	90

From the viewpoint of convergence of lines of current altitude none of the sets of data points to any one region as a localised seat of current concentration. But in all seasons the southward zenith distance is greater at Godhavn than Fort Rae, which result is consistent with regarding a region of the atmosphere south of Fort Rae as the average seat of disturbing current. Similarly, from the altitude angles for the two observatories next lower in latitude, Tromsö and Lerwick, we may infer that the region is generally north of Lerwick and is also north of Tromsö in winter, overhead at that station in the equinoctial months, and between the latitudes of Tromsö and

Lerwick in summer. But at Eskdalemuir and Rude Skov still farther south, the zenith distances measured to northward are consistently less than at Lerwick. In winter the position of current systems given by the altitude angle at both stations are to the south of the zenith. That this is not purely fortuitous is seen by examination of the altitude angles in Table 27 for the 14 individual days in the equinoctial months September, October, March, and April, in which the direction of the current flow is EW. at all six observatories. On 12 of these 14 days the altitude above the north horizon increases with decreasing latitude from Lerwick through Eskdalemuir to Rude Skov, while the south elevation angle increases from Godhavn to Fort Rae with decreasing latitude on 13 days.

§ 42. *Conclusions regarding current characteristics on disturbed days.*—Keeping in mind that all of the above results refer to the average conditions over 24-hour periods of disturbance the main inferences are:

(i) On the great majority of disturbed days the net balance of current flow is from E. to W. But it is known * that over a wide range of latitude and longitude the disturbance current in the high atmosphere flows from W. to E. in the local evening, and in the reverse direction only in the morning hours. With the exception of Fort Rae, the longitude differences of all the stations used above are sufficiently small and near to the Greenwich meridian to allow the same Greenwich day to represent local time conditions. It must therefore be inferred that with a few exceptions the total flow of EW. current in the early morning exceeds the WE. current in the later part of the day.

(ii) Since it is only the balance of EW. current flow that goes to produce the results of this inquiry it is not surprising that no rigorous definition of current localisation can be derived in this way. Nevertheless, the results here obtained support conclusions drawn from consideration of other data,* viz. that the distribution of current flow is both extensive and highly complex, that it varies with the season and magnitude of disturbance and also (though this is not illustrated by the present results) with the time of day.

Before leaving this question it is worth inquiring how far the magnitudes of the separate hourly vectors of the disturbance field at Fort Rae support the inferences of an EW. excess. Anticipating data to be discussed more fully later (§§ 52, 53) it is enough to say that this has been briefly examined by forming mean diurnal inequalities in H and Z for the two groups of 38 selected q' days and 40 d' days. Then by subtracting the q' from the d' values for corresponding hours, difference diurnal inequalities in H and Z were formed. The difference mean values $\delta H = Hd' - Hq'$ and $\delta Z = Zd' - Zq'$ could then be used in the same way as the daily departures for determining the current altitude and direction during each hour. In addition, the 24 hourly values of the resultant difference vector in the magnetic meridian plane $\sqrt{\delta H^2 + \delta Z^2}$ can be regarded as proportional to the mean hourly flow of current. The results, without giving the altitude angle, but only the position to N or S. of the station and direction of flow, are shown in Table 29. From this we see that the average hourly current flow is from E. to W. during the 13 Greenwich hours 5h to 18h, and W. to E. during the remainder of the day. The mean value of the resultant vector during the hours of EW. direction is exactly the same as for the 11 hours of reverse direction, viz. 129 γ, so we are led to infer that the consistent net balance of EW. flow arises from the excess of two hours during which the current is EW. If this result for Fort Rae is representative of all the stations whose data have been used in this inquiry, the surprise is not that the altitude angles should have failed to point to regions of concentration, but rather that such a large proportion of the individual days in such varied localities should have shown such a consistent current direction on such a small margin of excess.

§ 43. *Current system on quiet days.*—The other aspect of the results of figs. 4 and 5

* A. H. R. Goldie, Edinburgh, *Trans. Roy. Soc.*, vol. lvii, pt. i, pp. 143-176 (1931); and third paper cited on p. 15 of General Introduction to this volume.

and Tables 25 and 26 concerning the direction of current flow on quiet days has not been examined any farther than necessary to confirm that, at Godhavn, Tromsö, Lerwick, and Eskdalemuir, occasions of net EW. current are very largely in the minority. The difficulty in continuing the examination is to get an adequate basis from which to measure the departures ΔH and ΔZ. For whereas disturbance may be regarded either as due to current systems superposed on (or additional to) those acting on quiet days, or even, as some authorities consider is true of very high latitudes, merely a highly developed exaggeration of quiet-day conditions, to regard quiet conditions as in any way dependent on "average" conditions represented by all-day means lacks all support. If the months in which selected quiet days occur have been generally quiet, the differences between the daily values on the selected days and the all-day monthly mean will be small and the resulting current directions deduced from the signs of the departures ΔH and ΔZ highly variable. Therefore, though all of the 38 quiet days were found to have the same WE. current direction at Fort Rae on the local criteria of which station the days were selected, and likewise all of the 34 possible (*i.e.* complete) days at Tromsö had the same WE. direction, it is not surprising that four and three days respectively out of the total number of 38 at Lerwick and Eskdalemuir had reversed directions of net current flow.

TABLE 29.—RELATIVE MAGNITUDES AND POSITIONS OF CURRENT SYSTEM FOR EACH HOUR AT FORT RAE, FROM $d-q$ INEQUALITIES.

G.M.T. Hour Ending:	δH.	δZ.	√(δH² + δZ²).	Position and Direction.	G.M.T. Hour Ending:	δH.	δZ.	√(δH² + δZ²).	Position and Direction.
	γ	γ	γ			γ	γ	γ	
1	+138	− 83	161	S. WE.	13	− 74	+149	166	S. EW.
2	+126	− 95	158	S. WE.	14	− 97	+121	155	S. EW.
3	+ 78	−122	145	S. WE.	15	− 85	+125	151	S. EW.
4	+ 47	−143	150	S. WE.	16	− 98	+108	146	S. EW.
5	+ 20	−130	132	S. WE.	17	− 68	+ 45	82	S. EW.
6	− 27	− 12	129	N. EW.	18	− 25	− 4	25	N. EW.
7	− 55	− 74	92	N. EW.	19	+ 13	− 16	21	S. WE.
8	−135	− 15	136	N. EW.	20	+ 77	− 25	81	S. WE.
9	−117	+ 81	142	S. EW.	21	+113	− 20	115	S. WE.
10	− 76	+ 95	122	S. EW.	22	+129	− 27	132	S. WE.
11	−114	+126	170	S. EW.	23	+149	− 53	158	S. WE.
12	− 74	+149	166	S. EW.	24	+157	− 67	171	S. WE.

§ 44. *Considerations underlying application of non-cyclic change and use of Greenwich days in formation of diurnal inequalities.*—Using the De Bilt international selection of five quiet q and five disturbed d days per month, mean inequalities have been formed for each of the three primary elements H, D, and Z for all, q, and d days of each of the 13 months August 1932 to August 1933. In the formation of every inequality a correction has been applied to counteract the aperiodic change between the two Greenwich midnights determining the day. In view of the earlier discussion (§§ 35–37) relating to this change it is very questionable whether the application of a non-cyclic (n.c.) correction is really desirable; it is at least as questionable whether the use of the Greenwich day best serves the purposes of investigation of the majority of present-day magnetic phenomena. As regards the first of these questions, it has been shown (§ 37) that the n.c. change varies considerably with the hour from which the day starts—for data covering such a comparatively short period as a year both the sign and magnitude of the change depend much on the incidence of short period disturbance. A n.c. correction is a necessary preliminary to harmonic analysis of diurnal inequalities, but this is probably its only real justification as an essential part of the magnetic statistics of stations in high latitudes. The best course would be to publish two inequalities, one with and the other without the correction, but in the discussion of the Fort Rae data the corrections had already been incorporated in the inequalities before these considerations became clear. With the help of Table 19 suitable adjustments can be made for recovery of the uncorrected inequality.

Strict adherence to G.M.T. in all magnetic inequality formation is another matter requiring consideration. Except in such aspects of the subject as deal with the propagation of large scale disturbance following sudden commencements, all the phenomena of the earth's field which are periodic within 24 hours are related to the sun. Whether we are concerned with the regular quiet-day or disturbed-day variations or the daily variations of short period irregular disturbance, the characteristics are controlled not by Greenwich time but by local time. Therefore, since, for the discussion of universal time phenomena, recourse in any event must be had to the basic tabulations of hourly values, the mean inequalities being of no assistance in such investigations, the natural day to adopt is the local day. For the preparation of average *q* and *d* day inequalities according to the present international scheme the local day of the same name would be used in place of the period of 24 hours starting at the Greenwich midnight of the selected days. The differences in the final inequalities from, say, five selected quiet days produced by use of the local instead of the Greenwich day would probably be insignificant for observatories within two or three hours' longitude difference from Greenwich, but at stations such as Fort Rae, where disturbance is so prevalent, the eight hours separating the local and Greenwich midnight allow much scope for inclusion of irregular features not bargained for in the selection of days on the basis of data from observations within 30° or 40° of the Greenwich meridian. It is partly for this reason that one major argument in favour of Greenwich days, viz. the advantage of having strictly comparable periods of 24 hours at all stations represented by the inequalities, is largely invalid. Indeed, it is probably true that the measure of fruitfulness which has so far resulted from the use of the Greenwich day derives in large measure from the well-known fact that disturbed and quiet days occur together in groups, so that the tabulation of data referring to local day $\overline{n+1}$ in China and $\overline{n-1}$ in Alaska is partly concealed by the fact that both these days are likely to share the disturbed or quiet characteristics of the selected Greenwich day n (see also § 79).

In spite of these considerations, however, it was thought advisable in the formation of inequalities for Fort Rae to adhere to the present practice of using the Greenwich day as selected at De Bilt.

From the primary inequalities for H, D, and Z shown in Tables 212 to 220 of Vol. II inequalities of N, E, and I have been constructed using the relationships appropriate to the value of the field elements at Fort Rae:—

$$\begin{aligned} \delta N &= 0{\cdot}793\delta H - 1{\cdot}370\delta D. \\ \delta E &= 0{\cdot}609\delta H + 1{\cdot}784\delta D. \\ \delta I &= 0{\cdot}00727\delta Z - 0{\cdot}0563\delta H. \end{aligned}$$

These, for all, quiet, and disturbed days (G.M.T.), are given in Tables 221 to 229 of Vol. II. In the tables of inequalities for all components, primary and derived, the Augusts of 1932 and 1933 are shown both separately and combined. The annual inequality treats this average August as a single month along with the other eleven, and in a similar way the inequality representing summer conditions is derived from:

$$\tfrac{1}{4}\{\tfrac{1}{2}(\text{August 1932} + \text{August 1933}) + \text{May} + \text{June} + \text{July}\}.$$

As already explained, it is desirable for most purposes to picture the daily variations of the magnetic elements in terms of local time. The annual and seasonal inequalities for H, D, and Z have therefore been represented in fig. 6 as if they were derived from local day inequalities. Strictly, this simple equating of the two types of day is not possible, both because of the eight hours' difference in time and also

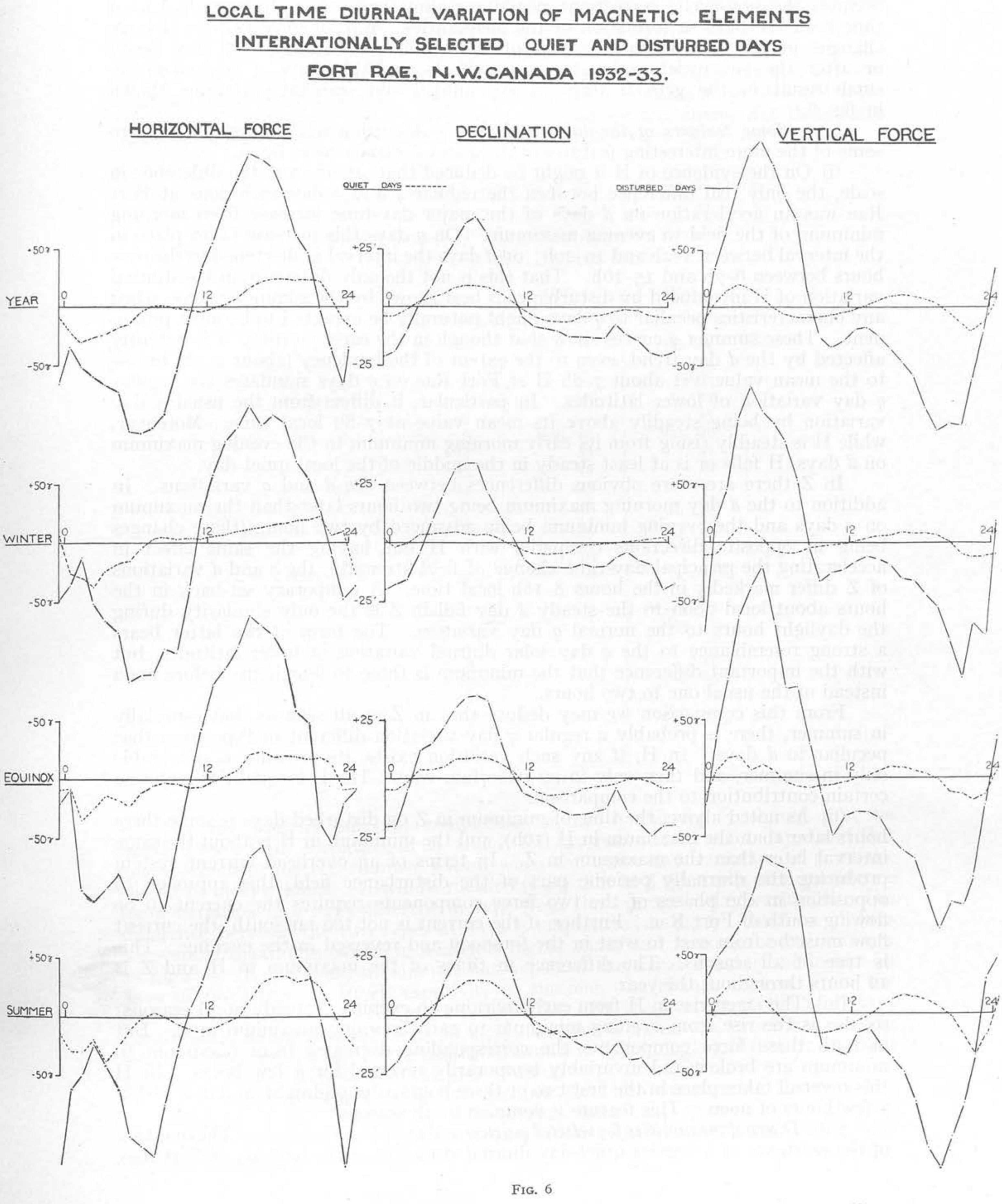

LOCAL TIME DIURNAL VARIATION OF MAGNETIC ELEMENTS
INTERNATIONALLY SELECTED QUIET AND DISTURBED DAYS
FORT RAE, N.W. CANADA 1932-33.
HORIZONTAL FORCE
DECLINATION
VERTICAL FORCE
QUIET DAYS
DISTURBED DAYS
YEAR
WINTER
EQUINOX
SUMMER
+50γ
-50γ
+25'
-25'
0
12
24

FIG. 6

because the non-cyclic corrections would certainly have been different had local time been the basis of formation of the inequalities. Except for occasions of large changes in the field in the interval of eight hours before the local day began or after the Greenwich midnight, these effects probably have a comparatively small result in the general form of the annual and seasonal variations shown in fig. 6.

§ 45. *Some features of the daily variations.*—Attention will be directed only to some of the more interesting features of the q and d variations in fig. 6.

(i) On the evidence of H it might be deduced that, apart from the difference in scale, the only real difference between the regular q and d day variations at Fort Rae was an acceleration on d days of the major day-time increase from morning minimum of the field to evening maximum. On q days this increase takes place in the interval between 1–2h and 19–20h; on d days the interval is shortened to the nine hours between 6–7h and 15–16h. That this is not the only difference in the diurnal variation of H introduced by disturbance is best shown by the summer curves, when any characteristics peculiar to q days might naturally be expected to be most prominent. These summer q curves show that though in the early morning H is patently affected by the d day trend, even to the extent of the tendency (about 2–3h) to rise to the mean value, yet about 7–8h H at Fort Rae on q days simulates the regular q day variation of lower latitudes. In particular, it differs from the usual d day variation by being steadily above its mean value at 7–8h local time. Moreover, while H is steadily rising from its early morning minimum to the evening maximum on d days, H falls or is at least steady in the middle of the local quiet day.

In Z there are more obvious differences between the d and q variations. In addition to the d day morning maximum being two hours later than the maximum on q days and the evening minimum being advanced by two hours (these changes being in opposite directions compared with H but having the same effect in accelerating the principal day-time change of field strength), the q and d variations of Z differ markedly in the hours 8–18h local time. A temporary set-back in the hours about local noon to the steady d day fall in Z is the only similarity during the daylight hours to the normal q day variation. The form of the latter bears a strong resemblance to the q day solar diurnal variation of lower latitudes, but with the important difference that the minimum is three to four hours before noon instead of the usual one to two hours.

From this comparison we may deduce that in Z in all seasons, but especially in summer, there is probably a regular q day variation different in type from that peculiar to d days. In H, if any such variation exists, its presence is detectable only in summer, and then only in an uncertain way. The D inequalities make no certain contribution to the comparison.

(ii) As noted above, the time of minimum in Z on disturbed days is some three hours later than the maximum in H (16h), and the minimum in H is about the same interval later than the maximum in Z. In terms of an overhead current system producing the diurnally periodic part of the disturbance field, this approach to opposition in the phases of the two force components requires the current to be flowing south of Fort Rae. Further, if the current is not too far south, the current flow must be from east to west in the forenoon and reversed in the evening. This is true of all seasons. The difference in times of the maximum in H and Z is 12 hours throughout the year.

(iii) The steep rise in H from early morning to evening is steady in all seasons; so also is the rise from evening minimum to early morning maximum in Z. But in both these force components the corresponding decreases from maximum to minimum are broken and invariably temporarily reversed for a few hours. In H this reversal takes place in the first two or three hours after midnight, and in Z within a few hours of noon. This feature is common to all seasons.

§ 46. *Diurnal inequalities for selected quietest and most disturbed days.*—The question of the existence of a regular quiet-day diurnal variation at the latitude of Fort Rae, different in type from that for d days, is of sufficient interest to merit further inquiry. Using as a criterion a combination of the quantities $HR_H + ZR_Z$ and $\overline{Hr_H + Zr_Z}$, where R is the extreme daily range, r the hourly range, and $\overline{}$ indicates the mean of the second quantity for the day (see also § 72), the 38 quietest and 40 most disturbed days during the 13 months were selected. These days are listed in Table 30. The seasonal mean inequalities corrected for n.c. change for these days are given in Tables 230 and 231 of Vol. II and represented in fig. 7.

TABLE 30.—LIST OF 38 QUIETEST AND 40 MOST DISTURBED DAYS.

Quietest Days.		Most Disturbed Days.	
1932.	1933.	1932.	1933.
Aug. 11	Jan. 4	Aug. 3	Feb. 21
19	5	27	22
24	10	28	23
Sept. 12	12	29	24
16	21	30	25
Oct. 6	Feb. 6	Sept. 20	Mar. 20
7	11	23	21
12	13	24	22
14	17	25	23
Nov. 7	Mar. 7	27	24
10	8	Oct. 15	25
24	9	21	Apr. 17
27	Apr. 12	Nov. 16	19
Dec. 7	May 12	Dec. 9	20
	26	14	21
	June 23	15	22
	July 13		May 1
	Aug. 1		6
	4		18
	10		June 13
	11		14
	12		July 24
	28		Aug. 5
	31		21

For the present purpose, comparison of fig. 6 and fig. 7 should first be made between the variation in H and Z for the two sets of quiet days and this again primarily for the summer season when the quiet day variation, if it exists, should be most evident. It will be recalled (§ 45) that in Z there was strong evidence for a variation in q days different in type from the average d day variation. The difference between the two types of days is emphasised in fig. 7. In Z on q' days an evening maximum, which in winter is higher than, and in equinox and summer as high as, the morning maximum, has replaced the usual evening minimum on days of disturbance. In H, especially in summer, the change in type from the q to the q' variation is even more remarkable. On the average of the 13 q' days contributing to the summer curve of fig. 7, the time of minimum, which was already retarded from $1\frac{1}{2}$h to $6\frac{1}{2}$h in the transition from q to d days (fig. 6), is further retarded to 11h on these q' days in equinox and summer.

It is therefore clear that on the quietest days the components H and Z are controlled by a force system different in type from that operating on disturbed days. In comparison with the variations in these components on the quieter days of lower latitudes it is remarkable that :—

LOCAL TIME DIURNAL VARIATION OF MAGNETIC ELEMENTS AT FORT RAE ON SELECTED QUIETEST AND MOST DISTURBED DAYS.

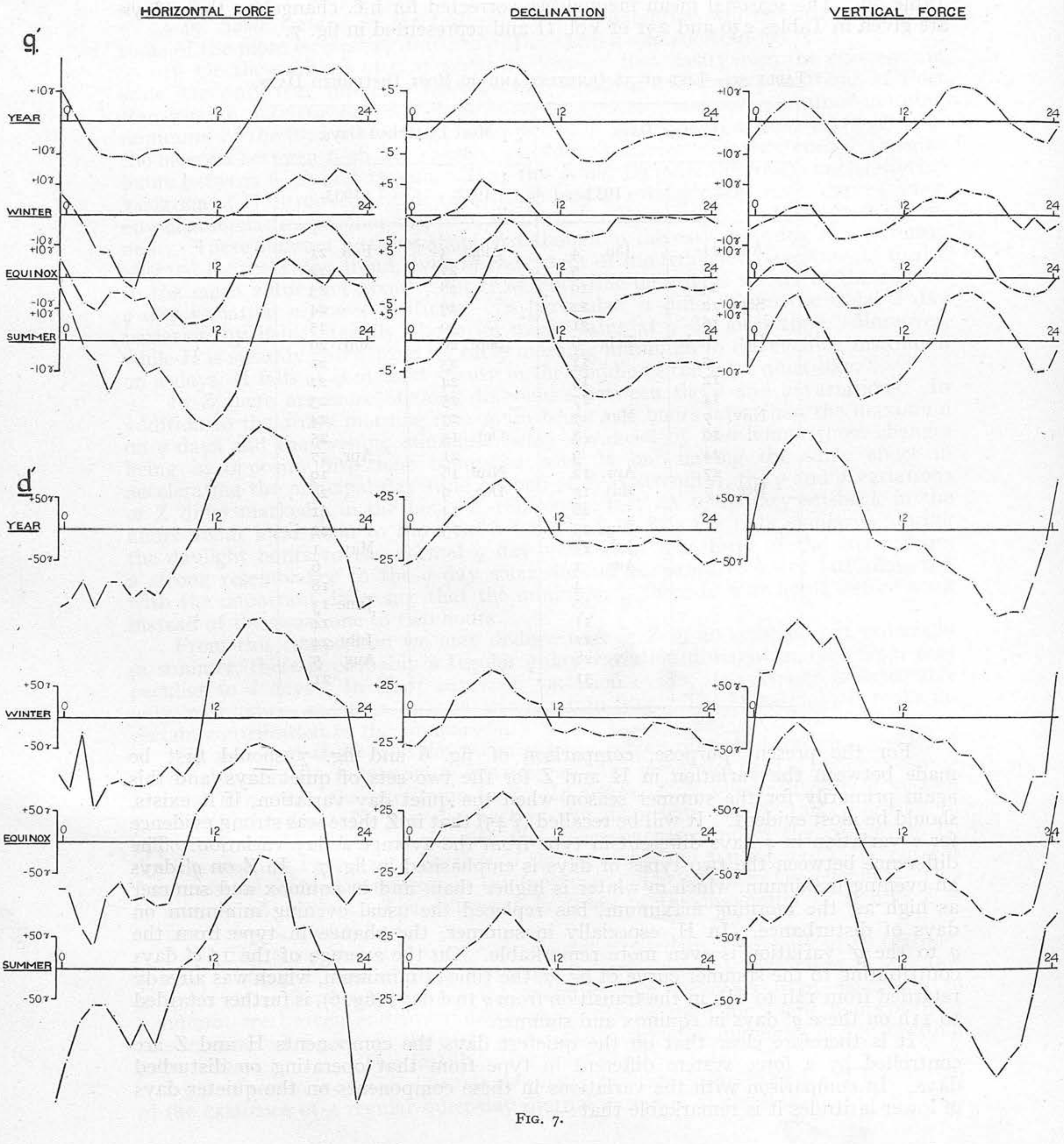


FIG. 7.

(i) The minimum in Z should precede noon by three to four hours; and

(ii) The range of this variation on the quietest days in the component Z at Fort Rae should be at least as great as that at such observatories as Lerwick, 6·5° lower in magnetic latitude.

Other aspects of the comparison offered by fig. 7 are more readily appreciated by the numerical characteristics of the inequalities to be discussed presently. It is worth noting, however, that, apart from scale and accidental irregularities arising from the comparatively small number of d' days, there is no difference between d and d' days comparable with that between the classes of q and q' groups.

§ 47. *Mean annual vector diagrams.*—From the seasonal mean inequalities of the three mutually perpendicular components N, E, and Z of the field, diagrams have been constructed to illustrate the diurnal variation of the field vectors in the three orthogonal planes:—

(*a*) the horizontal NE plane,
(*b*) the prime vertical EZ plane,
(*c*) the meridian NZ plane.

Fig. 8 shows one set of these diagrams as deduced from the annual mean inequalities for all days and for the international q and d days. A fourth group on the right of the figure is based on the difference $d-q$ inequalities derived by subtracting each hourly constituent of the q inequality from the corresponding d inequality. On the assumption that the effect of disturbance on the earth's field is to overlay quiet conditions by an additional system of forces, this fourth group of diagrams may therefore be considered as illustrating the diurnal changes in magnitude and orientation of the more purely disturbance field vector at Fort Rae.

Any one of the three sets of diagrams, say that for all days, in fig. 8 really represents the plan (NE), south elevation (EZ), and east elevation (NZ) of a 3-dimensional figure traced out by the ends of the resultant vector during the 24 hours of an average day. It therefore assists in the consideration of the various details of the diagram in any particular plane if the complete 3-dimensional figure of which that plane is only one aspect can be pictured. To provide this assistance, a model of such a figure for one of the classes of inequalities $d-q$ has been constructed by a process to be described later (§ 53), and fig. 8A shows two representations of this model, one from the east and one from the south. Models for other stations were constructed at the same time, and three of them were drawn with that for Fort Rae, but for the present purpose these others may be disregarded. Since fig. 8 shows that the separate vector diagrams for all and disturbed days closely resemble the diagrams constructed from the $d-q$ inequalities, it follows that the complete space figure represented by fig. 8A can be taken as representing also the all- and disturbed-day vectors.

From the drawings of the Fort Rae model it is clear that the 24-hourly resultant vectors all tend to cluster along one direction whose azimuth is approximately that of the mean magnetic meridian of the surface field, 37° E. of N. The drawings also show that this line of cluster is tilted above the horizon to the north at an angle of about 45°. The vector concentration is greater in the meridian plane than in the plane of tilt, where, indeed, the vectors spread out fanwise above and below the horizontal plane.

A little consideration shows that such an arrangement of the 24-hourly vectors is most easily interpreted in terms of an elevated electric current system lying to the south of Fort Rae and having its average direction nearly normal to the surface magnetic meridian. From an examination of the magnitudes and orientation of the hourly component vectors in the three planes it can further be inferred that the current sense is not always in one direction, but changes from being WE. in the evening hours to EW. in the morning. In the evening the WE. current is a maximum (or its distance from the station is least) at 19h local time and a maximum from EW.

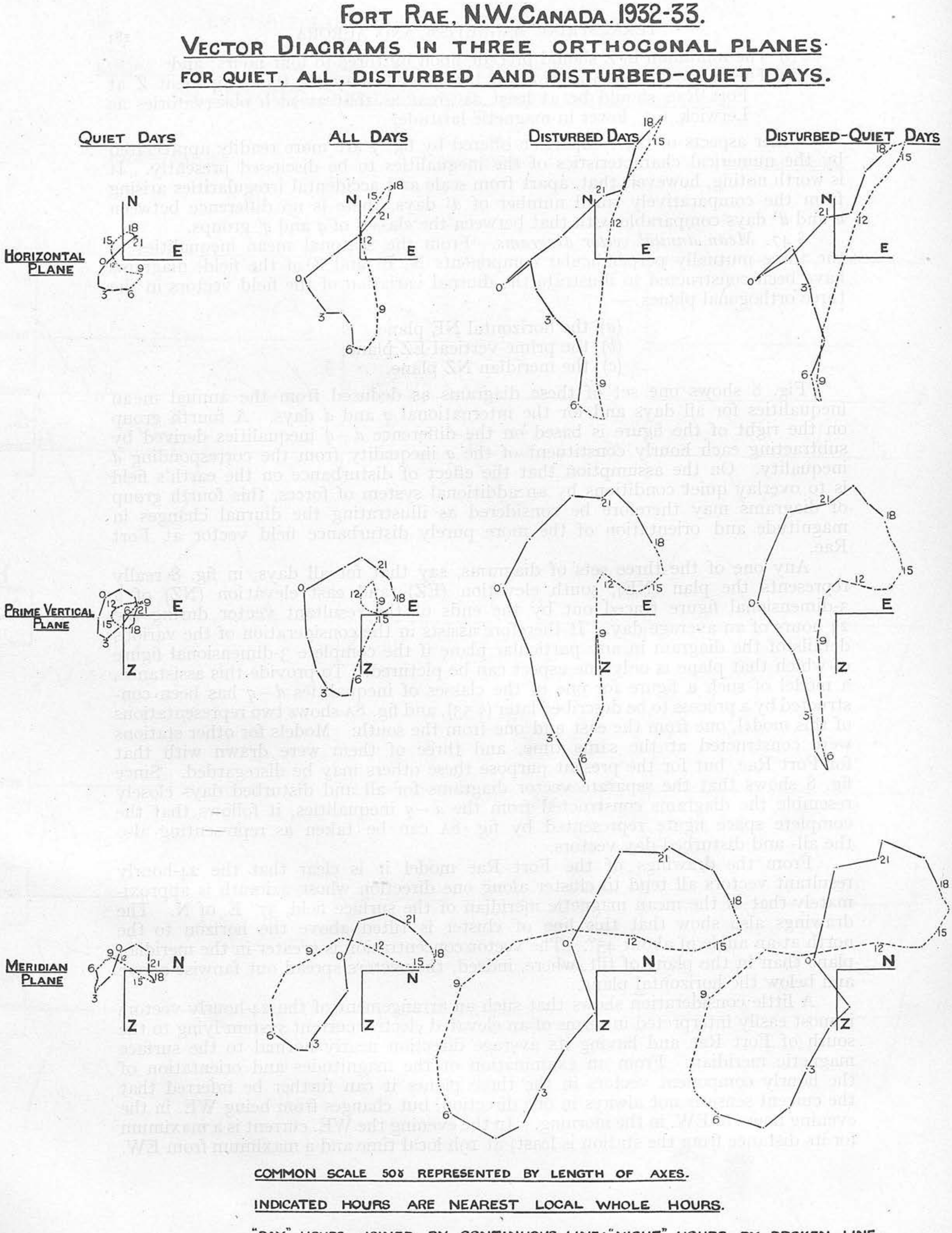

FORT RAE, N.W. CANADA. 1932-33.
VECTOR DIAGRAMS IN THREE ORTHOGONAL PLANES
FOR QUIET, ALL, DISTURBED AND DISTURBED-QUIET DAYS.
QUIET DAYS
ALL DAYS
DISTURBED DAYS
DISTURBED-QUIET DAYS
HORIZONTAL PLANE
PRIME VERTICAL PLANE
MERIDIAN PLANE
N
E
Z
COMMON SCALE 50γ REPRESENTED BY LENGTH OF AXES.
INDICATED HOURS ARE NEAREST LOCAL WHOLE HOURS.
"DAY" HOURS JOINED BY CONTINUOUS LINE: "NIGHT" HOURS BY BROKEN LINE.

FIG. 8.

at 6h. The time of reversal from WE. to EW. directed current is 0–1h local time and from EW. to WE. at 9–10h.

The description in foregoing paragraphs refers to the all, d, or $d-q$ vectors. Although the q day diagrams in fig. 8 resemble those for the other classes of days, especially, as it appears, in the simpler form taken by the meridian (NZ) plane vectors, there are fairly strong grounds for inferring that the q day diagrams are not simply miniatures of the d day diagrams. This aspect, however, can be more advantageously

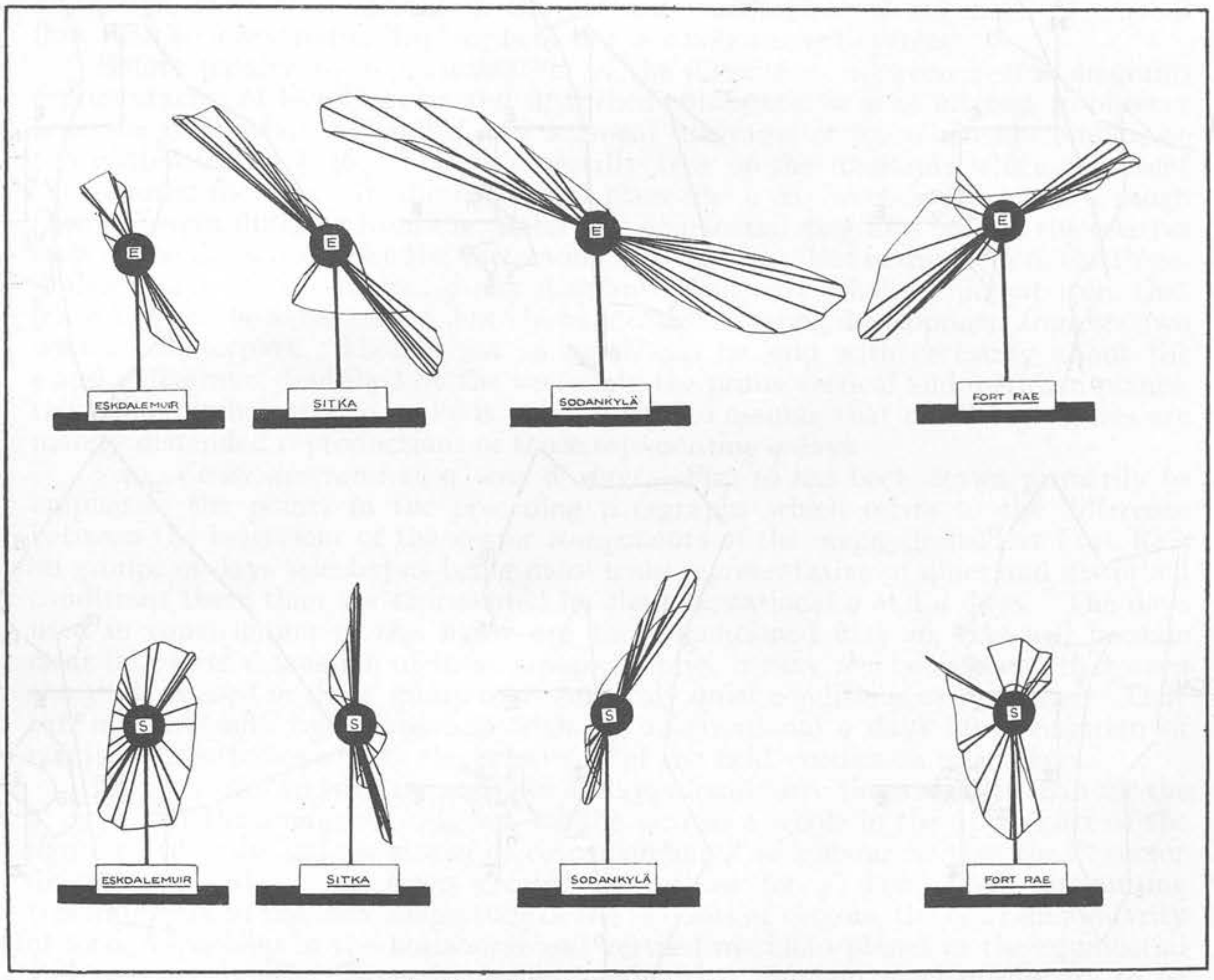


FIG. 8A.—Disturbance field vector models.

The upper figures show the models as viewed from the east (*i.e.* they represent the vectors in the meridian plane); the lower figures show the models viewed from the south (*i.e.* they represent the vectors in the prime vertical plane).

The lengths of the bases on which models stand represent 50 γ for Eskdalemuir, 75 γ for Sitka, 75 γ for Sodankylä, and 150 γ for Fort Rae.

considered with the aid of other diagrams constructed from inequalities derived from days more truly representative of quiet and disturbed conditions at Fort Rae (§ 49).

§ 48. *Seasonal vector diagrams.*—The three sets each of six diagrams in fig. 9 show the forms taken in the three seasons by the annual q and d diagrams of fig. 8. Confining attention first to the dominant d day diagrams, and in particular to those representing the diurnal variation in the horizontal plane, we see that from the winter to the summer months the arrangement of the individual hourly vectors undergoes a considerable change. All three seasonal diagrams have this in common, that, though highly irregular, they are in the main directed along the magnetic meridian. But this clustering about the meridian is much more developed in winter than in the equinoctial months and more in these months than in summer. In summer the direction of rotation of the vector is clearly and consistently anticlockwise; in winter there is no predominant direction. In both the prime vertical and

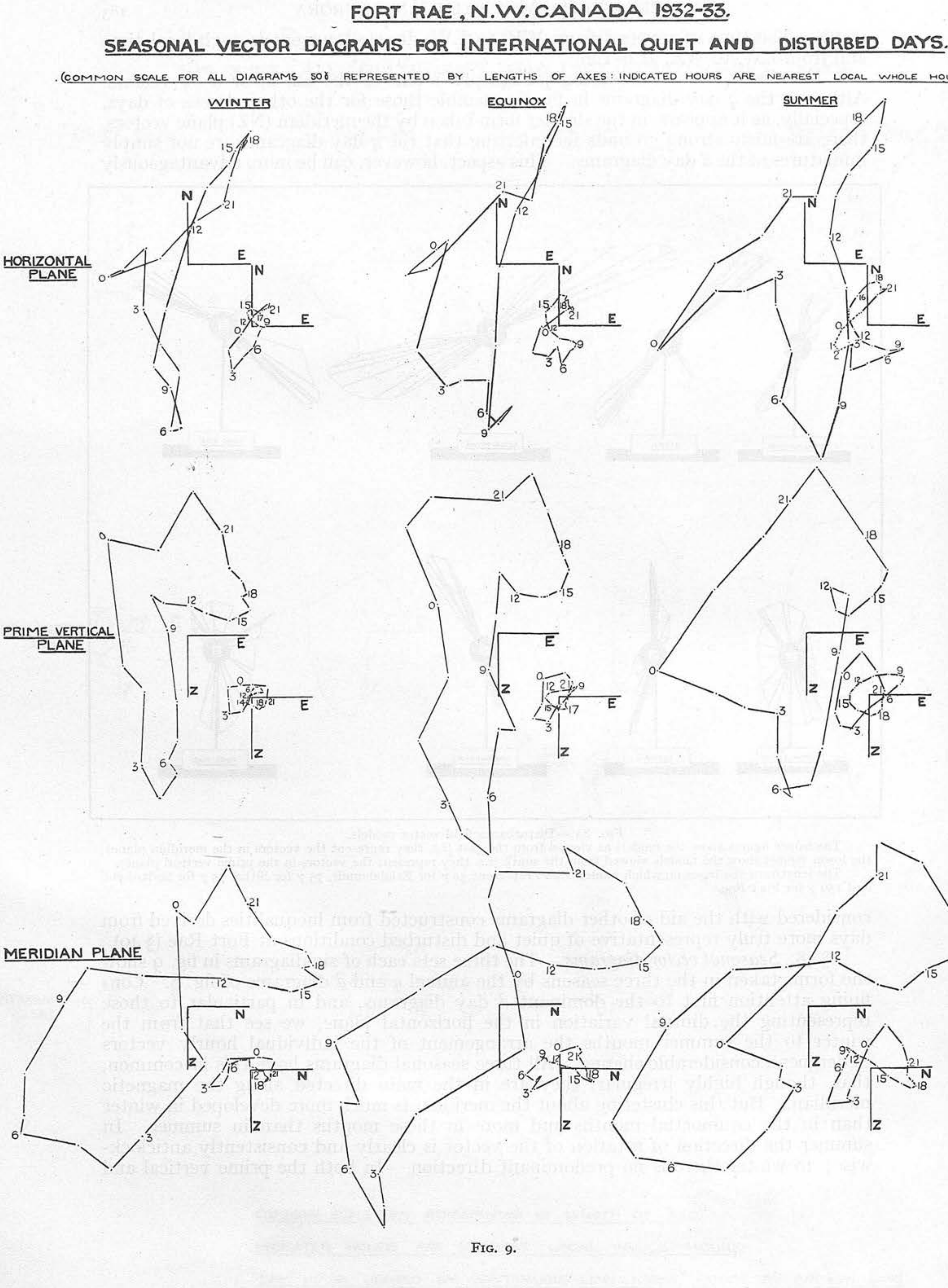

FORT RAE, N.W. CANADA 1932-33.
SEASONAL VECTOR DIAGRAMS FOR INTERNATIONAL QUIET AND DISTURBED DAYS.
(COMMON SCALE FOR ALL DIAGRAMS 50γ REPRESENTED BY LENGTHS OF AXES: INDICATED HOURS ARE NEAREST LOCAL WHOLE HOURS.)
WINTER
EQUINOX
SUMMER
HORIZONTAL PLANE
PRIME VERTICAL PLANE
MERIDIAN PLANE
N
E
Z

FIG. 9.

meridian plane diagrams of fig. 9 seasonal changes of a different nature are only slightly less prominent; in the former, in particular, the change is mainly one of form; in the latter, of tilt relative to the horizontal plane.

In conjunction with similar diagrams from other stations these seasonal variations in the form of the vector diagrams have been interpreted * as pointing to seasonal changes in the position and concentration of the current system producing disturbance. So far as the evidence of the Fort Rae data goes, the variations are to be attributed more to a change in the vertical distribution of the lines of current flow than to a horizontal displacement of the whole current system.

Before passing to an examination of the differences between vector diagrams representative of locally quiet and disturbed conditions, it is of interest to observe how the international *q* and *d* day seasonal diagrams of fig. 9 already emphasise the contention of § 46. This is especially true of the diagrams which represent the summer months. In the horizontal plane the *q* day vectors trace out a rough figure-of-eight differing from the winter and equinoctial diagrams only in the relative sizes of the areas traced by the vectors in the two loops; but in distinction, the three-limbed shape of the summer *d* day diagram is not only wholly different from that for *q* days in the same season, but shows a clear unfolding development from its own winter counterpart. Though not so much can be said with certainty about the *q* and *d* diagrams described by the vectors in the prime vertical and meridian planes, they differ sufficiently to make it unjustifiable to assume that the *d* day figures are merely distended reproductions of those representing *q* days.

§ 49. *Vector diagrams on* q′ *and* d′ *days.*—Fig. 10 has been drawn primarily to emphasise the points in the preceding paragraphs which relate to the difference between the behaviour of the vector components of the magnetic field at Fort Rae, on groups of days selected as being more truly representative of quiet and disturbed conditions there than are represented by the international *q* and *d* days. The days used in construction of this figure are those mentioned in § 46. As will become clear in a later discussion of these groups of days, it may not be assumed that even the 38 days used in the *q′* group represent truly quiet conditions at Fort Rae. They can indicate only by comparison with the international *q* days how reduction of residual disturbance affects the behaviour of the field vectors on quiet days.

Fig. 10 is drawn with the scale for *d′* days already five times smaller than for the *q′* days, but the average *q′* diagram for the year as a whole in the upper part of the figure is still only half the size of its corresponding *d′* neighbour, so that the *d′* vector diagrams are about ten times greater than those for *q′* days. But discounting this difference in the mere magnitude of the two sets of vectors, the clear dissimilarity of form, especially in the horizontal and vertical meridian planes in the equinoctial and summer months, leaves it unquestionable that different mechanisms are to be held responsible for the vector changes on the two types of days. In the horizontal plane in both those seasons the *q′* diagrams are fairly regular crescent shapes, having their main axes running north and south, and with the times of change from north- to south-directed component vectors at 9h and 21h local time in equinox, and 10½h and 22h in summer. In the same plane the corresponding *d′* diagrams are highly irregular, directed roughly along the magnetic meridian and with times of change from N. to S. component vector approximately at 5½h and 18½h in both equinox and summer. Similar equally prominent differences exist between the two types of diagrams in the vertical meridian plane. In particular, the main direction of vectors on *d′* days is inclined to the horizontal at 45° or 50°, so indicating that the N and Z vectors are approximately equal; on *q′* days the vertical component is small compared with the horizontal component, so that the resulting figure swept out lies very largely in the horizontal plane.

Now at stations such as Lerwick the quiet-day diurnal variations are already so shallow compared with those for average disturbed conditions that it might have been assumed that the further increase of 6° in magnetic latitude from Lerwick to

* London, *Proc. Roy. Soc.*, A, **152**, pp. 277–298 (1935).

FORT RAE, N.W. CANADA. 1932-33.

VECTOR DIAGRAMS IN THREE ORTHOGONAL PLANES FOR SELECTED QUIETEST (q′) AND MOST DISTURBED (d′) DAYS.

(SCALE FOR q′ DAYS FIVE TIMES SCALE FOR d′ DAYS: INDICATED HOURS ARE G.M.T.)

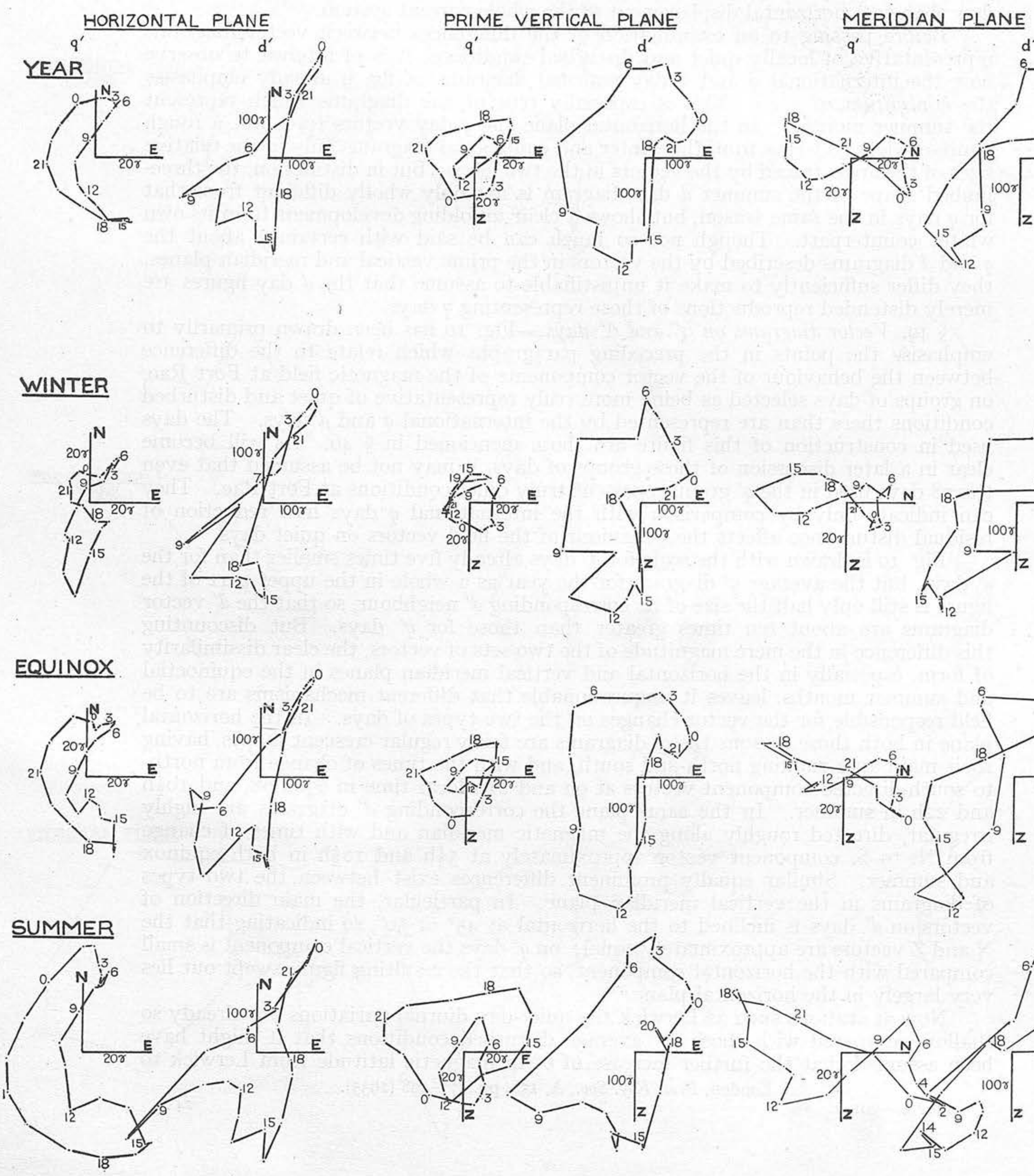


FIG. 10.

Fort Rae would have seen the complete disappearance of any purely quiet-day variation, different, that is, in type from the disturbed-day variation. The above comparison between the vector diagrams on q' and d' days at Fort Rae, however, makes it clear that there exists, even at this station, a diurnally varying force field peculiar to the quietest conditions to be found there, and that it is by no means negligible compared with that at more southerly stations.

§ 50. *The total field vector T and its positional co-ordinates.*—A more direct method of examining the behaviour of the force vectors of the diurnally varying field at any station is to compute for each hour the total resultant vector T and its positional co-ordinates ϕ and θ, where ϕ is the angle measured from north through east which the vertical plane containing T makes with the vertical plane through the geographical meridian, and where θ is the inclination of T to the vertical measured from the nadir. If ΔN, ΔE, and ΔZ are the three corresponding component departures of the field at any one instant (or over an interval of time of, say, one hour) from some normal value, then

$$T^2 = \Delta N^2 + \Delta E^2 + \Delta Z^2$$

$$\phi = \tan^{-1}\frac{\Delta E}{\Delta N}$$

and

$$\theta = \tan^{-1}\frac{\rho}{\Delta Z},$$

ρ being the resultant vector in the horizontal plane.

On the view of the disturbance field expressed in § 47, suitable normal values on which to base an examination of the hourly mean force vectors of this field are the corresponding hourly mean values on quiet days, and therefore the departures ΔN, ΔE, and ΔZ of the difference $d-q$ inequalities for these three components have been formed. Table 31 gives the 24 resulting values of T, ρ, θ, and ϕ. In the same

TABLE 31.—VALUES OF T, ρ, θ, AND ϕ AT EACH HOUR FROM $d-q$ AND $d'-q'$ INEQUALITIES.

G.M.T. Hour Ending:	$d-q$.												$d'-q'$.				Zonal Mean Hour Ending:
	Year.				Winter.				Summer.				Year.				
	T.	ρ.	θ.	ϕ.	T.	ρ.	θ.	ϕ.	T.	ρ.	θ.	ϕ.	T.	ρ.	θ.	ϕ.	
h	γ	γ	°	°	γ	γ	°	°	γ	γ	°	°	γ	γ	°	°	h
1	120	105	116	27	97	89	114	25	134	117	120	32	162	139	121	29	17
2	119	97	120	25	103	95	113	24	127	89	135	27	159	128	127	27	18
3	121	77	128	20	102	88	120	23	139	58	155	10	146	81	146	22	19
4	111	40	134	20	83	57	136	23	141	25	170	355	151	47	162	28	20
5	99	35	133	351	92	36	157	25	107	35	151	313	133	26	169	355	21
6	95	38	132	266	86	17	168	329	73	42	145	265	130	33	165	251	22
7	72	59	120	258	108	24	167	264	69	69	90	260	99	66	138	251	23
8	67	67	98	253	88	57	140	266	129	119	68	236	148	147	96	241	24
9	49	36	58	285	46	37	53	292	57	46	53	263	149	127	57	240	1
10	57	29	50	260	62	39	40	335	44	26	37	262	122	78	40	232	2
11	89	32	47	220	94	20	13	265	39	10	15	284	170	114	42	217	3
12	123	43	47	204	128	43	20	201	72	8	7	280	168	78	28	200	4
13	146	62	48	187	128	69	33	184	127	41	19	196	170	81	29	193	5
14	157	101	53	191	161	119	48	187	158	95	37	201	162	108	42	192	6
15	157	119	57	187	157	126	53	185	179	122	43	191	163	105	40	181	7
16	150	124	61	185	145	132	65	187	178	143	53	187	163	122	48	181	8
17	109	106	78	188	103	103	90	194	101	96	71	179	98	86	62	180	9
18	62	60	104	189	94	89	108	203	49	47	105	203	39	39	96	168	10
19	31	13	132	165	51	45	118	205	33	29	120	266	28	23	125	92	11
20	45	38	118	28	31	23	120	13	47	41	120	40	81	77	108	30	12
21	71	68	105	29	58	55	108	20	68	67	99	32	116	114	100	30	13
22	87	85	102	33	82	81	100	28	84	83	98	38	132	129	102	33	14
23	107	102	106	33	90	88	102	27	111	105	108	40	158	149	110	34	15
24	124	115	110	30	109	106	103	28	131	120	113	36	172	158	113	31	16

table are shown the corresponding values of these vector characteristics derived from the separate seasonal $d-q$ inequalities representing winter and summer, and also for the more extreme class of $d'-q'$ inequalities as a whole.

For the q and q' inequalities alone, Table 32 supplies an exactly similar set of data.

TABLE 32.—VALUES OF T, ρ, θ, AND ϕ AT EACH HOUR FROM q AND q' INEQUALITIES.

G.M.T. Hour Ending:	*q* Days.												*q′* Days.				Zonal Mean Hour Ending:
	Year.				Winter.				Summer.				Year.				
	T.	ρ.	θ.	ϕ.	T.	ρ.	θ.	ϕ.	T.	ρ.	θ.	ϕ.	T.	ρ.	θ.	ϕ.	
h	γ	γ	°	°	γ	γ	°	°	γ	γ	°	°	γ	γ	°	°	h
1	26·6	24·2	66	12	15·6	13·3	59	28	38·0	34·5	65	4	21·2	17·8	57	5	17
2	26·1	24·4	69	16	17·7	15·9	64	29	39·9	37·3	69	11	21·1	18·0	59	11	18
3	25·6	24·6	74	21	18·5	16·9	66	33	37·4	35·7	73	17	19·4	17·5	64	17	19
4	23·2	23·0	82	24	19·7	18·6	71	37	31·4	31·0	81	20	17·4	16·7	75	20	20
5	23·6	23·1	102	31	19·8	19·7	55	38	33·4	33·1	98	24	16·1	16·1	91	22	21
6	26·4	22·4	122	27	24·6	22·8	112	36	32·6	26·9	125	16	18·3	17·9	102	24	22
7	24·5	10·9	154	359	13·3	7·5	146	8	38·4	13·6	159	332	15·7	14·7	110	19	23
8	20·7	15·0	134	258	15·2	11·0	134	242	28·0	21·6	130	263	12·5	10·9	120	13	24
9	23·7	23·5	82	241	28·7	27·0	110	227	34·6	31·8	67	240	5·9	5·7	104	342	1
10	33·6	30·3	65	225	29·8	29·8	86	218	39·4	31·0	52	231	6·8	6·1	65	254	2
11	33·8	27·9	56	208	40·6	38·6	72	207	33·3	19·7	36	222	11·7	9·9	58	211	3
12	30·5	26·3	60	198	26·8	24·3	65	199	47·8	38·8	54	202	13·9	12·2	62	194	4
13	24·7	23·2	70	184	19·8	19·6	80	191	32·3	30·0	68	181	14·9	14·3	74	179	5
14	24·2	24·2	90	168	18·3	17·5	107	180	27·2	27·2	89	150	19·4	19·4	90	166	6
15	21·9	20·6	109	142	12·7	9·1	134	159	34·1	33·0	104	128	21·3	20·7	104	155	7
16	22·1	19·9	116	127	10·6	6·9	139	102	36·5	33·7	113	122	24·0	22·1	113	151	8
17	21·5	19·2	117	125	9·8	8·6	119	94	35·4	31·2	118	127	24·2	21·2	118	152	9
18	17·3	14·6	122	136	6·9	5·5	127	92	30·2	24·9	124	140	21·9	19·0	120	171	10
19	10·5	7·3	136	164	4·6	3·9	122	18	22·2	16·3	133	165	17·7	15·5	119	194	11
20	8·3	6·0	134	246	6·8	6·7	101	337	17·2	12·5	133	212	15·9	14·6	113	226	12
21	9·7	9·4	104	297	10·2	10·1	84	338	13·4	11·3	122	258	14·8	14·5	101	260	13
22	13·8	13·8	86	314	11·8	11·4	75	339	16·1	16·0	95	290	14·3	14·3	50	288	14
23	17·4	16·5	72	331	14·0	13·0	68	356	21·4	20·7	75	312	14·7	14·0	72	312	15
24	23·2	21·4	67	354	14·2	13·1	67	3	28·4	25·7	65	341	19·2	16·3	58	340	16

§ 51. *Seasonal mean values of T and ρ in disturbance.*—The mean of the 24 hourly values of T (Table 33) deduced from the annual $d-q$ inequalities is 98·7 γ; for winter and summer the corresponding means are 95·8 γ and 99·8 γ. Since the corresponding seasonal values of ρ are proportionally similar to those of T, the disturbance field, both in respect of its horizontal and vertical component vectors, must be equally developed in these two extreme seasons.

On the $d'-q'$ class of days T is 35% greater than on $d-q$ days.

TABLE 33.—MEAN VALUES OF T AND ρ DURING "DAY" AND "NIGHT" HOURS.

	$d-q$.						$d'-q'$.	
	Year.		Winter.		Summer.		Year.	
	T.	ρ.	T.	ρ.	T.	ρ.	T.	ρ.
24 Hours (γ) . . .	98·7	68·8	95·8	68·3	99·8	68·1	134	94
Day (γ) . . .	98·5	86·0	93·4	85·9	103·5	88·3	123	106
Night (γ) . . .	98·8	51·6	98·2	50·7	96·1	47·8	146	82
Night/Day . . .	1·00	0·60	1·05	0·59	0·93	0·54	1·19	0·77

§ 52. *Diurnal variation of T and ρ in disturbance.*—The diurnal variation of T on $d-q$ days is illustrated in fig. 11. Throughout the year the variation is dominated by a primary maximum in the morning hours and by a less regular secondary maximum in the evening. From a time which varies from one hour after midnight in winter to three hours in summer, T rises steeply to the main maximum of the day (at 5–6h winter and 6–8h summer), then falls equally steeply to the main

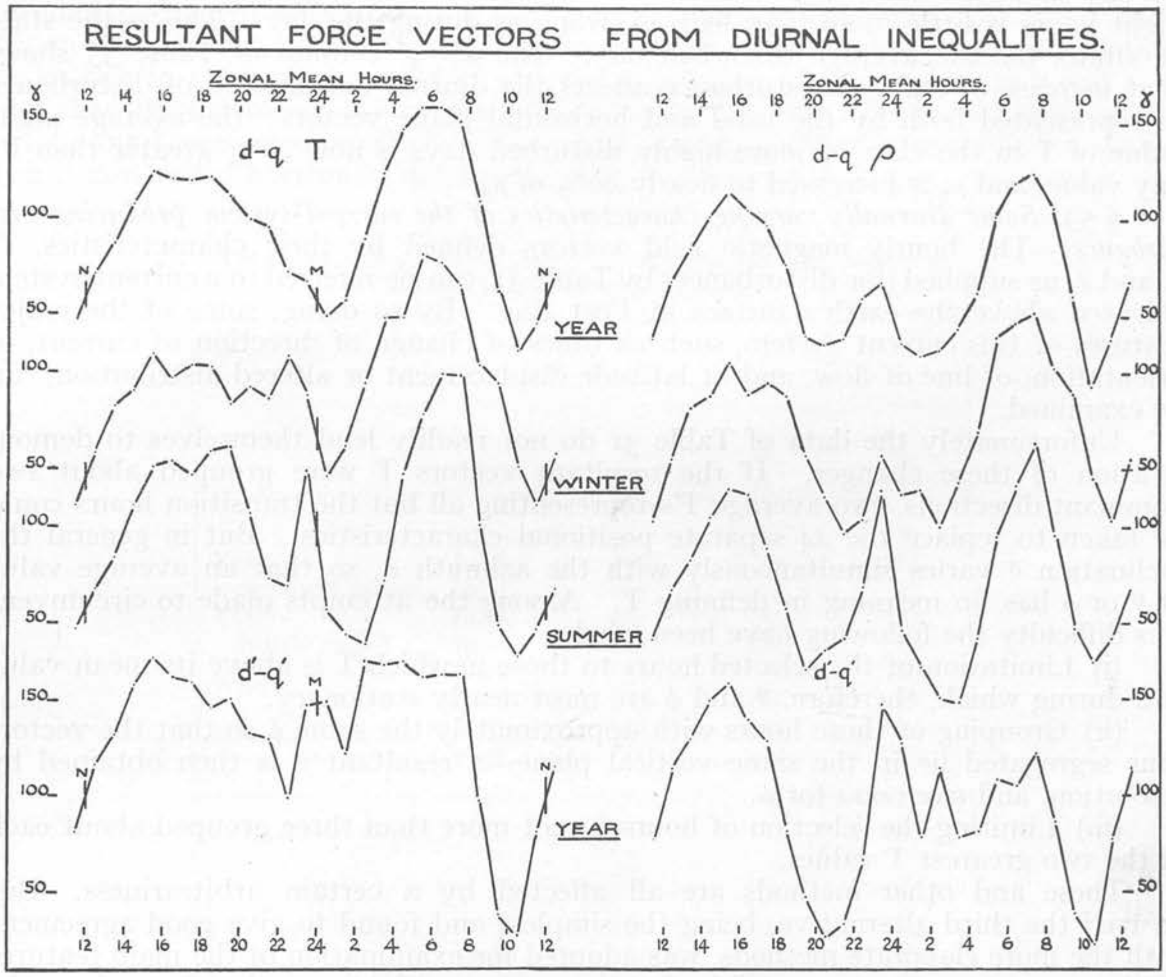


FIG. 11.

minimum just before noon in winter, 10–11h in summer. The second maximum is an irregular plateau of high T values from $15\frac{1}{2}$h to just before midnight. In these evening hours the summer variation differs from the winter variation in that the plateau is less broad, falling sharply after 20h but rising again in a short-lived third peak in the hour before midnight. On the right of fig. 11 are plotted the corresponding diurnal variations of ρ. From these it is clear that the third (pre-midnight) maximum of T in summer derives primarily from the horizontal vectors in which this third maximum is indeed also present in winter, though with much less emphasis. In the main it is a contribution from the E force component.

By comparison with the variations of T and ρ from $d-q$ inequalities, the variations of those quantities computed from $d'-q'$ inequalities (represented by the lowest curves of fig. 11) are not only less regular but have the morning maximum much less well developed in relation to the two evening humps. In particular, the variation of the $d'-q'$ T is dominated by a single minimum two to three hours before noon and by an irregular persistence of high values from 15h through midnight to 8h.

Defining the "day" hours as 7h to 18h inclusive and the remaining 12 as "night" hours, Table 33 shows the $d-q$ day and night mean values of T and ρ for the year as a whole and the seasons separately, and the $d'-q'$ values for the complete set of days; the last line gives the night/day ratios. This table emphasises the inferences from fig. 11 by showing that the total disturbance vector T is almost equally developed in the day and night hours, though a little more by night than by day in winter than in summer. But the vector in the horizontal plane in the night hours is little more than half as strong as during the day. This is the state of affairs for the average disturbed day. The $d'-q'$ column of Table 33 shows that increase of scale of disturbance affects the diurnal distribution of disturbance as represented both by the total and horizontal plane vectors; the average night value of T in the class of more highly disturbed days is now 20% greater than its day value, and ρ_n is increased to nearly 80% of ρ_d.

§ 53. *Some diurnally varying characteristics of the current system producing disturbance.*—The hourly magnetic field vectors defined by their characteristics, T, θ, and ϕ, as supplied (for disturbance) by Table 31, can be referred to a current system elevated above the earth's surface at Fort Rae. By so doing, some of the major features of this current system, such as times of change of direction of current, of orientation, of line of flow, and of latitude displacement or altered distribution, can be examined.

Unfortunately the data of Table 31 do not readily lend themselves to demonstration of these changes. If the resultant vectors T were grouped about two dominant directions, two average T's representing all but the transition hours could be taken to replace the 24 separate positional characteristics. But in general the inclination θ varies simultaneously with the azimuth ϕ, so that an average value of θ or ϕ has no meaning in defining T. Among the attempts made to circumvent this difficulty the following have been tried:—

(i) Limitation of the selected hours to those in which T is above its mean value and during which, therefore, θ and ϕ are most nearly stationary.

(ii) Grouping of those hours with approximately the same ϕ so that the vectors thus segregated lie in the same vertical plane—a resultant θ is then obtained by resolution, and *vice versa* for ϕ.

(iii) Limiting the selection of hours to not more than three grouped about each of the two greatest T values.

These and other methods are all affected by a certain arbitrariness. But on trial the third alternative, being the simplest and found to give good agreement with the more elaborate methods, was adopted for examination of the main features of the current system responsible for the vectors. Table 34 therefore gives the values of T, θ, and ϕ, at the two times each day when T is greatest. In the upper $(d-q)$ part of the table these times (denoted by a.m. and p.m.) all refer to the same groups of three hours, viz. for a.m. 5–8h, and for p.m. 15–18h zonal mean time. A second set of values of T, θ and ϕ are given for the year to show that values for the single hours of real maxima (a.m. 6h, p.m. 16h) may be practically identical with means for three hours grouped about them. In the lower part of Table 34 relating to $d'-q'$ two sets of a.m. values are shown, since the time of real a.m. maximum of $d'-q'$ T is advanced compared with $d-q$ T from 5–8h to 2–5h; the hours of maximum in the evening 15–18h remain the same for the $d'-q'$ as for the $d-q$ data. In the subsequent discussion of the contents of Table 34 T a.m. will be used to denote the morning maximum vector and T p.m. to denote the vector which is either a primary or secondary maximum in the evening hours.

As an example of the interpretation of Table 34, the first line shows that for the year as a whole T a.m. at Fort Rae is oriented 8° west of south and 57° from the (downward) vertical, while from the second line it is to be inferred that by the evening hours the vector has swung round into the NE. quadrant, so that T p.m. is 27° east of north and is now directed 25° above the horizontal plane. Referring these vector positions to a current system suitably oriented to produce them, we can confirm earlier inferences (*cf.* §§ 40 and 47) that for the year as a whole such a disturbing current lies southward of Fort Rae both a.m. and p.m., and that its direction is reversed from being east-west a.m. to west-east p.m. From the difference in inclination θ to the vertical of the two vectors it may be further inferred that the current system moves northward so as to be more nearly above Fort Rae in the evening than in the morning, or alternatively that it alters its vertical distribution to be at a greater average height above the surface. And accompanying this horizontal displacement or vertical redistribution, the change in ϕ shows that the current system has veered between the morning and evening hours. It is to be noted that the change in the magnitude of T, which accompanies those changes in θ and ϕ, is such that the alteration in current distribution produces a diminished field at the surface and therefore supports the view of an evening increase in mean height rather than a northward horizontal displacement.

TABLE 34.—MAGNITUDE AND ORIENTATION OF A.M. AND P.M. MAXIMUM RESULTANT VECTORS.

		T.	θ.	ϕ.
d − q.				
		γ		°
Year (grouped values)	a.m.	155	57	188
	p.m.	121	115	27
Year (single value)	a.m.	157	53	191
	p.m.	124	110	30
Winter	a.m.	154	55	186
	p.m.	103	110	26
Summer	a.m.	172	44	193
	p.m.	131	123	33
d′ − q′.				
Year	a.m. 2–5h	169	33	203
	a.m. 5–8h	163	43	185
	p.m. 15–18h	164	120	29

§ 54. *Change in position of disturbing current with season.*—The separate seasonal values of the vector characteristics in Table 34 confirm that the average daily changes in current distribution and orientation just described are effective both in winter and summer, the veer from a.m. to p.m. being the same (20°) in both. Comparison of the a.m. and p.m. values of θ for those two seasons gives the further information, that throughout the day the current system is either bodily farther south in summer than in winter or is at a lower height above the surface. If the first of these alternatives is valid, the southward summer displacement must be associated with a substantial increase in current concentration to account for the greater T in both a.m. and p.m. in that season.

§ 55. *Effect of increased scale of disturbance on the current system.*—Consideration of the T, θ, and ϕ values for $d' - q'$ days in the lower part of Table 34 brings out some interesting differences and similarities compared with those in the corresponding $d - q$ part of the table. Both T a.m. and T p.m. are naturally greater on $d' - q'$ days; in addition, they are more nearly equal to each other than on $d - q$ days, when, on the average of the year, T a.m. exceeded T p.m. by 28% (winter 50%; summer

31%). As regards inclination of the vector to the vertical, increase of scale of disturbance, represented by the change from $d-q$ to $d'-q'$ days, is similar to the change from winter to summer in the $d-q$ days alone. This implies that on days of greatest disturbance the disturbing current system (both a.m. and p.m.) is removed farther southward from Fort Rae than on days of disturbance. And to account for the difference in magnitude of T as well as θ this displacement must be accompanied by an increased concentration of the lines of current flow, or alternatively the mean height must be lowered. On either hypothesis the change is more marked for the east-west, a.m., current direction than for the west-east, p.m., current.

The effect of increased disturbance on the azimuth of the current is equally conspicuous. When the values of ϕ in Table 34 are compared for the hours of real maxima in T (*i.e.* 2–5h in $d'-q'$ with 5–8h in $d-q$ and 15–18h in both) there is a veer from the less to the more disturbed days. The average of the a.m. and p.m. azimuths of T on $d-q$ days is 17·5°; on $d'-q'$ it is 26°. Now the azimuth of the surface magnetic meridian at Fort Rae is 37·5°, and the azimuth of the magnetic axis pole relative to Fort Rae is 24°. On both sets of days the line of current flow is therefore more nearly normal to the line joining the station to the axis pole than to the magnetic meridian, and, more especially on the more disturbed days, the a.m. and p.m. positions of the current are respectively only 1° west and 5° east of the normal to the line joining the station to the axis pole.

The methods of examining the seasonal and diurnal characteristics of the disturbing current system outlined in foregoing paragraphs have been applied to data for six stations in addition to Fort Rae. The results of this more extensive examination have been published separately.*

§ 56. *T and ρ on quiet days.*—Table 35 summarises the mean of the 24-hourly values of T and ρ given in each of the four sections of Table 32. On the average

TABLE 35.—MEAN VALUES OF T AND ρ ON QUIET DAYS.

	q.						q'.	
	Year.		Winter.		Summer.		Year.	
	T.	ρ.	T.	ρ.	T.	ρ.	T.	ρ.
24 Hours (γ)	22·2	19·6	17·1	15·5	31·2	26·6	16·8	15·4
Day (γ)	18·2	16·4	11·2	9·8	27·7	24·8	19·2	17·3
Night (γ)	26·2	22·9	22·9	21·1	34·7	28·4	14·3	13·4
Night/Day	1·44	1·40	2·05	2·15	1·25	1·15	0·74	0·77

of the year T_q is 22% of T_{d-q} and $T_{q'}$ is only 13% of $T_{d'-q'}$. In contrast with the approximate equality of T_{d-q} in winter and summer, the winter T_q is only 55% of T_q in summer. These differences give further strong grounds in support of the contention that the mechanism producing the quiet-day vectors is controlled by seasonally varying factors different from those operative in disturbance.

Differences in the development of T during the day and night hours on the two classes of days are equally conspicuous, though in an unexpected way. The night/day ratios of T_{d-q} were approximately unity throughout the year (Table 33); with increased scale of disturbance the ratio increased to 1·19. On the general class of q days, however, the annual value of the ratio is 1·44, but with the larger seasonal range of from 1·25 in summer to 2·05 in winter. On the selected q' days

* London, *Proc. Roy. Soc.*, A, 152, pp. 277–298 (1935).

the ratio falls to 0·74. This low value gives the clue to the explanation of the high values of the ratio on q days.

Judging by the change in type of the three component force diurnal variations in figs. 6 and 7 on classes of days of progressively less disturbance, it can be inferred that the resulting vector T on an ideally quiet day would be greatest in the daylight hours and uniformly low in the night hours. The average value of T on such a day would be small throughout the day. No day at Fort Rae, however, was perfectly quiet, but from the mode of selection a smaller proportion of q than q' days approached this condition. Therefore, since any trace of disturbance introduces the much more emphatic T_d variation with maxima in the morning and evening hours, it is to be expected that the day-time value of T_q is easily swamped by its value in the night hours. It is only in the specially selected q' class of days, when the disturbance contribution is reduced to a minimum, that the real relationship between the night

TABLE 36.—MONTHLY AND SEASONAL VALUES OF INEQUALITY RANGE (IR) AND AVERAGE DEPARTURE (AD) OF H, D, AND Z INEQUALITIES.

Month and Season.	Horizontal Force.						Declination.						Vertical Force.					
	Inequality Range.			Average Departure.			Inequality Range.			Average Departure.			Inequality Range.			Average Departure.		
	All.	*q.*	*d.*	All.	*q.*	*d.*	All.	*q.*	*d.*	All.	*q.*	*d.*	All.	*q.*	*d.*	All.	*q.*	*d.*
	γ	γ	γ	γ	γ	γ	′	′	′	′	′	′	γ	γ	γ	γ	γ	γ
1932 Aug.	158·8	55·4	459·0	45·5	16·0	105·1	50·5	24·5	99·7	10·9	6·5	17·9	125·4	54·4	298·2	33·5	11·9	89·6
Sept.	161·3	48·3	334·1	47·2	14·5	92·9	43·7	19·6	88·9	10·5	5·2	20·5	141·7	39·2	365·9	33·5	8·3	90·6
Oct.	138·6	62·5	426·2	43·2	12·9	93·8	32·5	16·1	72·1	9·2	4·1	17·9	138·1	46·3	354·4	30·8	9·9	83·3
Nov.	121·4	71·2	232·9	37·7	13·4	72·1	30·9	14·8	60·6	7·0	3·2	12·4	104·4	40·9	245·3	23·2	8·8	55·4
Dec.	155·0	134·0	308·6	44·8	25·7	83·1	28·5	14·1	60·3	7·1	2·9	13·8	102·2	52·7	281·5	21·6	8·2	60·1
1933 Jan.	122·2	43·1	273·3	38·8	9·9	63·5	26·5	9·8	73·0	6·7	2·1	12·3	81·0	23·3	186·2	20·0	6·1	38·0
Feb.	136·6	37·3	360·5	40·3	8·8	92·7	25·5	8·0	74·6	7·0	1·9	17·9	113·0	27·5	388·5	24·6	5·0	80·8
Mar.	124·6	51·3	272·5	39·3	10·1	78·7	34·2	12·6	68·4	8·9	3·7	15·8	138·3	30·6	400·3	33·5	4·8	77·3
Apr.	157·3	109·9	281·6	49·0	22·9	67·0	44·3	20·6	62·0	11·2	6·1	15·8	138·8	76·1	268·2	38·5	12·6	64·2
May	130·3	108·9	319·1	38·7	17·4	73·0	40·7	24·8	89·7	11·2	6·8	21·1	120·0	46·4	253·4	28·3	10·9	53·5
June	151·4	83·3	301·7	38·4	21·4	66·1	45·3	26·6	80·8	11·7	7·7	18·9	131·8	92·1	330·7	33·0	18·6	79·7
July	139·9	116·3	321·4	35·1	20·6	67·1	37·7	24·5	56·2	9·2	7·5	13·6	132·9	106·7	342·8	28·3	18·3	63·4
Aug.	145·0	68·3	286·1	38·9	15·3	76·2	38·1	23·8	69·3	9·9	6·4	18·8	111·4	38·6	307·3	26·3	9·8	70·7
Mean Aug.	146·2	54·9	315·8	41·0	15·0	86·7	43·3	23·5	80·6	10·8	6·4	17·9	112·4	39·4	258·3	29·8	10·4	76·1
y	128·7	53·7	237·3	40·3	14·1	72·4	34·1	15·6	60·3	9·1	4·6	15·9	115·2	41·0	246·4	27·6	8·9	64·6
w	126·8	60·7	232·8	39·6	13·6	70·7	24·7	9·0	54·1	6·9	2·3	13·7	96·2	23·6	246·9	21·2	6·3	54·3
e	139·9	54·1	249·6	44·1	13·6	78·8	37·7	16·1	59·5	9·9	4·6	17·0	133·8	36·9	307·8	33·6	8·1	76·5
s	132·1	71·1	273·1	38·4	17·3	70·6	40·8	24·4	73·2	10·6	7·0	17·7	118·6	63·8	266·6	29·1	14·1	65·9

and day values of T_q becomes noticeable. Since the winter inequalities of the quiet-day separate component vectors are so shallow compared with those for summer, it follows that the effect of disturbance on the winter value of the night/day ratio will be much more pronounced than in the corresponding ratio for the summer months. This is borne out by the ratios in Table 35.

§ 57. *Range and average departure of the diurnal inequalities.*—In addition to the change in type from q to d day variations examined in earlier paragraphs, it is at once obvious from figs. 6 and 7 that disturbance involves a very great change in scale. This aspect of the comparison is well summarised by the values of the ranges of the several mean inequalities (to be denoted by IR to distinguish them from the absolute daily ranges R) and the average departures (AD), these latter being defined as the means of the 24-hourly constituents of the inequalities irrespective of sign. When the form of the variation is not simple the AD is probably a better comparative measure than the IR of the average forces producing the variations. At the same time it will be understood that, since the average value over 60-minute intervals is the basis of both quantities, neither give any indication of the contributions to the total diurnal activity of the forces involved in the short period irregular perturbations superposed on the regular changes in all but the quietest hours.

For all days and for the internationally selected q and d days Table 36 shows IR and AD for the three elements H, D, and Z, and Table 37 gives the d/q ratios

TABLE 37.—MONTHLY VALUES OF THE RATIOS $\frac{IR_d}{IR_q}$ AND $\frac{AD_d}{AD_q}$

Month and Season.	H (γ). IR.	H (γ). AD.	D ('). IR.	D ('). AD.	Z (γ). IR.	Z (γ). AD.
1932 Aug.	8·3	6·6	4·1	2·8	5·5	7·5
Sept.	6·9	6·4	4·5	3·9	9·5	10·9
Oct.	6·8	7·3	4·5	4·4	7·2	8·4
Nov.	3·3	5·4	4·1	3·9	6·0	6·3
Dec.	2·3	3·2	4·3	4·5	5·3	7·3
1933 Jan.	6·4	6·3	7·4	5·9	8·0	6·2
Feb.	9·7	10·5	9·3	9·4	14·1	16·2
Mar.	5·3	7·8	5·4	4·3	13·1	16·1
Apr.	2·6	2·9	3·0	2·6	3·5	5·1
May	2·9	4·2	3·6	3·1	5·5	4·9
June	3·6	3·1	3·0	2·5	3·6	4·3
July	2·8	3·3	2·3	1·8	3·2	3·5
Aug.	4·2	5·0	2·9	2·9	8·0	7·2
y	4·4	5·1	3·9	3·5	6·0	7·3
w	3·8	5·2	6·0	6·0	10·5	8·6
e	4·6	5·8	3·7	3·7	8·3	9·4
s	3·8	4·1	3·0	2·5	4·2	4·7

of these quantities. Basing the comparison primarily on the AD ratios of Table 37 (which in fact are very similar to those for the IR) we see that the effect of disturbance is to increase the scale of the regular diurnal variation 7-fold in Z, 5-fold in H, and 3½-fold in D. In all three elements the increase in the AD is least in summer, but this is probably as much due to the large AD of the summer variation on

TABLE 38.—SEASONAL MEAN VALUES OF IR AND AD ON q' AND d' DAYS AND THEIR RATIOS.

(In H and Z the Inequality Range is given to the nearest whole γ.)

Season.	H. IR. q'	H. IR. d'	H. IR. d'/q'	H. AD. q'	H. AD. d'	H. AD. d'/q'	D. IR. q'	D. IR. d'	D. IR. d'/q'	D. AD. q'	D. AD. d'	D. AD. d'/q'	Z. IR. q'	Z. IR. d'	Z. IR. d'/q'	Z. AD. q'	Z. AD. d'	Z. AD. d'/q'
	γ	γ		γ	γ		'	'		'	'		γ	γ		γ	γ	
y	31·9	290	9·1	11·1	90·9	8·2	15·2	64·6	4·3	4·0	16·5	4·1	23·0	294	12·8	6·0	82·7	13·8
w	39·0	309	7·9	8·4	94·9	11·3	9·7	61·6	6·3	1·9	15·8	8·3	16·1	310	19·3	4·4	79·4	18·0
e	32·3	324	10·0	9·8	97·9	10·0	15·9	71·1	4·5	3·8	16·3	4·3	21·9	313	14·3	5·1	88·3	17·3
s	53·3	394	7·4	15·6	91·0	5·8	23·4	79·2	3·4	6·5	18·2	2·8	34·0	316	9·3	9·5	85·7	9·0

q days (especially in Z) as to a real disturbance effect. The combination of those two causes is well illustrated in the separate monthly ratios for February and July, of which the former provides the largest ratio values for all three components and the latter the smallest for Z and D and among the smallest for H.

It will be understood from the earlier discussion on the general features of the diurnal variations of the elements that the data derived from inequalities based on the ordinary international q and d days hardly represent quiet and disturbed conditions at Fort Rae. Table 38 therefore gives the seasonal mean values of IR and AD derived from the inequalities of the 38 q' and 40 d' days selected as being the quietest and most disturbed days in the Polar Year at Fort Rae. This table also gives the ratios d'/q' of these quantities corresponding with the d/q ratios in Table 37. We now see that, instead of the 5-fold increase in AD for the average of the three elements in Table 37, the corresponding increase from q' to d' days is nearly 9-fold. It should be noted that this great difference between the two selections of days is not to be attributed solely to retaining only a very limited number of the most highly disturbed days in the d' class, for this class has two-thirds of the number of d days though not necessarily two-thirds of the same days (§ 78). Another interesting feature of those AD ratios is that it is very largely the effect of greater disturbance in the H and Z variations which accounts for the large differences in average ratio mentioned above. Except in winter the limitation of the q and d days to those which are at least locally quieter and more disturbed has no substantial effect on the daily variations in D. It is also worth noticing that when the groups of days representing disturbance are selected by local criteria, there is no significant difference between the seasons in the values of the AD of the average variations in the three elements.

TABLE 39.—VALUES OF IR AND AD ON q AND d DAYS AT LERWICK, 1932–33, AND THEIR RATIOS.

Aug. 1932–Aug. 1933.	H (γ).		D (').		Z (γ).	
	IR.	AD.	IR.	AD.	IR.	AD.
q	29·9	7·2	7·7	1·8	12·7	2·9
d	88·9	19·7	15·5	3·8	132·5	32·4
d/q	3·0	2·7	2·0	2·1	10·4	11·2

§ 58. *Comparison of inequality range and average departure at Fort Rae with those at other stations.*—To afford rough comparison of the magnitude of disturbance at Fort Rae with a station only 6·5° lower in magnetic latitude, Table 39 gives the IR and AD values from the same q and d days at Lerwick as used in Table 37 for Fort Rae. For H and D on q days both the IR and AD values at Fort Rae are approximately double those at Lerwick; for Z the Fort Rae values are about three times as great. As will already be clear from the differences between q and d and q' and d' characteristics at Fort Rae, these inter-station differences will be largely affected by the mode of selection of the days, and the international selection must naturally be dominated by conditions in Western Europe and therefore be more

TABLE 40.—d/q RATIOS FOR IR AND AD AT CAPE EVANS, CAPE DENISON, FORT RAE, AND LERWICK.

	Magnetic Latitude.	H (γ).		D (').		Z (γ).	
		IR.	AD.	IR.	AD.	IR.	AD.
Cape Evans . .	S. 78·9°	3·2	3·1	2·9	3·4	2·2	2·2
Cape Denison .	S. 75·5	4·3	4·5	2·5	3·1	2·1	2·1
Fort Rae . .	N. 69·1	4·4	5·1	3·9	3·5	6·0	7·3
Lerwick . . .	N. 62·6	3·0	2·7	2·0	2·1	10·4	11·2

favourable to Lerwick (§§ 44 and 79). In spite, however, of any such deficiencies in the selection of days, it will be noted that the d/q ratios both for IR and AD at Fort Rae exceed those for Lerwick in the diurnal inequalities for H and D. Almost entirely due to the very small quiet-day IR and AD values in Z at Lerwick, on the other hand, the d/q ratios for that element are more than 50% greater than for Fort Rae. From Table 40 it is of interest to note that at two stations, Cape Denison and Cape Evans, in magnetic latitudes higher than that of Fort Rae, and during years not less quiet than 1932–33, the increases in the inequality range and average departure from quiet to disturbed days were similar to those for Fort Rae in H (summer) or D (equinox), but in the vertical component the d/q ratio was only 2 as compared with 7 at Fort Rae and 11 for Lerwick. Since it is known that below the latitude of Lerwick the ratio again decreases, the effect of disturbance on the scale of the vertical component variation must be a maximum about the latitude of that station.

§ 59. *Comparison with 1882–83 inequality ranges.*—The Polar Year 1932–33 was a period of low magnetic activity. It would be instructive to estimate disturbance effects at Fort Rae in a really disturbed year. Now the relative sunspot numbers

TABLE 41.—RANGE OF MEAN DIURNAL VARIATION ON QUIET DAYS.

Month and Season.	H.	D.	Z.
	γ	′	γ
1882 Sept.	113	29·3	87
Oct.	55	22·5	35
Nov.	63	14·0	47
Dec.	47	16·9	98
1883 Jan.	123	23·4	58
Feb.	72	20·2	82
Mar.	60	18·7	80
Apr.	63	24·1	73
May	110	34·2	123
June	100	35·0	103
July	57	30·0	40
Aug.	40	24·5	49
1882–83 *y*	75	24·4	73
w	76	18·6	71
e	73	23·7	69
s	78	30·9	79
1932–33 *y*	54	15·6	41
w	61	9·0	24
e	54	16·1	37
s	71	24·4	64

for 1882 and 1883 covering the months of the First International Polar Year were 59·7 and 63·7, corresponding with 11·1 and 5·7 for 1932 and 1933. The Bartels' u_1 measures of magnetic activity are 70 and 57 for 1882 and 1883, as compared with 40 for 1932 and 36 for 1933. 1882 was the year of maximum solar activity in its cycle, 1933 a minimum. Thus 1882–83 would be a good year to compare with 1932–33. Unfortunately, however, the technique of observation at Fort Rae differed so greatly in the two years that a basis of comparison of the magnetic results is not readily achieved. The hourly values tabulated for 1882–83 are the means of three instantaneous eye readings of the variometer instruments at each hour. In view of results from 1932–33 to be discussed later (§ 65), showing that the average extreme range within each hour was 92 γ in H, 76 γ in Z, and 25·6′ in D, it will be clear that in the more disturbed conditions of 1882–83 the hourly eye readings can hardly be expected to give more than the general trend of the variations in the three components except on quiet days. The ranges of the monthly mean inequalities for those comparatively quiet days in 1882–83—an average of about five days per month contributing to the inequalities—are given in Table 41, in which the corresponding seasonal means for 1932–33 are repeated for comparison. From this table it is seen that *q* day ranges for 1882–83 exceed those for 1932–33 by 56% in D, 39% in H, and 78% in Z, or 58% in the average of the three components. Discounting the *a priori* expectancy of an increased range in the earlier year, solely from the use of instantaneous as compared with mean hourly values, 58% is certainly not greater than might have been expected from the difference in activity of the two years. At the same time, earlier paragraphs in this section dealing with the differential effect of disturbance on the three components might have been interpreted as giving grounds for expecting the percentage increases for H and D to be interchanged.

That such comparisons cannot lead to results of value will be further emphasised when the extreme daily ranges (R) in the two years are compared (§ 64). It will then be seen that corresponding with average values of R for 1882–83 of 413 γ, 313 γ, and 107·7′ in H, Z, and D respectively, the figures for 1932–33 are 506 γ, 451 γ, and 135·6′. In large part the differences here shown arise from the fact that whereas R for the earlier year are the differences of the extremes of the highest and lowest of the hourly readings each day, those for 1932–33 are the absolute extremes at whatever instants the components attained their maxima and minima.

§ 60. *Estimate of elevation of disturbing current system from IR and AD.*—The examination of the regular disturbance variations of H and Z (§ 53) has shown that the current system effective in producing disturbance at Fort Rae lies to the south

TABLE 42.—VALUES OF ELEVATION ANGLES OF CURRENT SYSTEM FROM IR AND AD FOR $d-q$ AND $d'-q'$ INEQUALITIES.

Season.	IR.		AD.	
	$d-q$.	$d'-q'$.	$d-q$.	$d'-q'$.
	°	°	°	°
y	42	44	46	46
w	38	43	50	49
e	36	45	44	47
s	45	50	46	45

of the station. It is also known (§ 47 and figs. 8 and 8A) that though the disturbance vectors at Fort Rae are not oriented in the direction of the earth's magnetic axis pole in such a simple way as, for example, at Sodankylä, there is nevertheless a tendency of the vectors to cluster along this direction. The angle

$$\theta = \tan^{-1}\{\mathrm{IR(H)}/\mathrm{IR(Z)}\},$$

where IR is the range of the mean inequality on disturbed days, might therefore be expected to indicate the elevation above the (south) horizon at which the disturbing current system lies. If, however, a different force field on *q* days, having its own distinctive diurnal variation, still exists on disturbed days though completely masked then, a better estimate of θ would be derived from

$$\theta = \tan^{-1}\{(\mathrm{H}_d - \mathrm{H}_q)/(\mathrm{Z}_d - \mathrm{Z}_q)\},$$

where H_d and H_q represent the inequality range (or average departure) on *d* and *q* days in H. Values of θ derived from the mean inequalities of the whole year and the seasons for the classes of ordinary *q* and *d* days and the more limited selection of *q′* and *d′* days are given in Table 42. Computed from such different characteristics of the diurnal variation as the range and the average departure, it is surprising that the four estimates of θ for the year are so consistent in giving a mean elevation of about 45° for the current system. In view of the superiority

(i) of the d', q' data in representing disturbance and quiet at Fort Rae, and
(ii) of the average departure in representing the force system producing the diurnal variation,

the fourth column of Table 42 probably gives the best estimates of θ. The seasonal values of θ in this column indicate that the current system undergoes a systematic seasonal variation in position, from being highest or most northerly in winter to lowest or most southerly in summer. This inference is in agreement with conclusions about the seasonal characteristics of the disturbing current arrived at from a detailed study of the orientation of force vectors at those hours each day when the vectors are greatest (§ 54). It should be said, however, that this confirmation does not indicate that values of the angle θ derived by the method outlined can be effectively used to replace estimates of the position of the current system based on more elaborate though more rigorous methods. If the substratum of q' days underlying the inequalities of d' days were (reasonably) ignored and θ derived from the simpler expression above, the following values of θ would be obtained:—

	y.	*w.*	*e.*	*s.*
From d' IR	45°	45°	46°	51°
From d' AD	48	48	48	46

The inter-agreement between these and the $d'-q'$ values in Table 42 implies that the opposite direction of seasonal change in the distribution of the current system is at least as consistently upheld by the IR data as that indicated by the average departures. The reason probably is that the changes in the distribution of the lines of overhead current flow are too complex to be measured by such simple means.

§ 61. *Harmonic analysis of regular diurnal variations.*—The annual and seasonal mean inequalities of H, D, and Z for all days and for the international quiet and disturbed days have been analysed for expression in the series

$$\Sigma(a_n \cos 15nt + b_n \sin 15nt),$$

where t is reckoned in hours from Greenwich midnight. Table 43 gives the values for the pairs of constants a, b for the components of 24, 12, 8, and 6 hours' wave-length. In Table 44 the values of the constants c, α in the alternative mode of expression

$$\Sigma c_n \sin (15n\mathrm{T} + \alpha_n)$$

are shown, the epoch in this table being corrected to the more useful local mean midnight. Table 45 shows the local times of maximum of each of the four waves corresponding with the values of α in Table 44.

Though necessary for detailed inquiry, the information contained in these three tables is inconvenient for ready interpretation. The most important aspects are more readily comprehended when represented in the form of harmonic dials. Fig. 12 illustrates all the essential features of the analysis. In this figure the radial lines represent local hours, the number in each part of the figure corresponding with the wave-length. Distances measured from the centre of the concentric circles are amplitudes—the distances between successive circles in fig. 12 for the 24-hour wave representing 10 γ for H and Z with the approximate equivalent of 5′ in D. The amplitude scale of the 12-hour wave is double, and the scales of the 8-hour and 6-hour waves are ten times the scale for the 24-hour wave in fig. 12. Distinctive heavy lines (continuous for H, long broken for Z, and short broken for D) connect the annual mean positions for the three classes of days, quiet, all, and disturbed; subsidiary thin lines

TABLE 43.—HARMONIC COMPONENTS OF THE DIURNAL INEQUALITY OF THE MAGNETIC ELEMENTS.

Values of a_n, b_n in the series $\Sigma(a_n \cos 15nt^\circ + b_n \sin 15nt^\circ)$, t being reckoned in hours from midnight G.M.T. (Longitude of Fort Rae, 116° 4′ W.)

Season.	Horizontal Force.								Declination.								Vertical Force.							
	a_1.	b_1.	a_2.	b_2.	a_3.	b_3.	a_4.	b_4.	a_1.	b_1.	a_2.	b_2.	a_3.	b_3.	a_4.	b_4.	a_1.	b_1.	a_2.	b_2.	a_3.	b_3.	a_4.	b_4.
	All Days.																							
	γ	γ	γ	γ	γ	γ	γ	γ	′	′	′	′	′	′	′	′	γ	γ	γ	γ	γ	γ	γ	γ
w	+ 60·1	+ 9·3	− 6·2	+ 7·0	− 3·6	− 0·3	+ 2·7	− 4·4	− 7·8	− 4·3	+ 1·9	+ 7·0	+ 1·6	− 0·6	+ 0·5	− 0·4	− 19·7	− 4·4	+ 31·7	− 4·7	− 11·0	+ 4·4	− 0·8	− 3·1
e	+ 67·3	+ 3·9	+ 8·0	+ 3·5	− 6·8	+ 7·6	+ 3·6	− 1·1	− 10·8	− 8·2	+ 1·7	+ 8·5	+ 0·1	− 0·9	− 0·7	− 2·0	− 40·0	− 7·5	+ 38·0	− 11·2	− 5·9	+ 3·1	− 5·6	+ 2·5
s	+ 57·4	+ 7·0	+ 10·6	+ 12·6	− 5·5	+ 8·7	+ 5·3	− 7·2	− 9·4	− 12·1	− 0·3	+ 8·5	+ 1·1	− 0·6	− 0·9	− 1·2	− 34·3	− 5·1	+ 34·2	− 11·9	− 2·5	+ 1·9	− 4·2	+ 2·3
y	+ 61·6	+ 6·7	+ 4·1	+ 7·7	− 5·3	+ 5·3	+ 3·9	− 4·2	− 9·3	− 8·2	+ 1·1	+ 8·0	+ 0·2	− 1·0	− 0·4	− 1·2	− 31·3	− 5·7	+ 34·6	− 10·2	− 6·4	+ 3·1	− 3·5	+ 0·6
	Quiet Days.																							
w	+ 18·6	− 0·4	− 7·2	+ 10·6	− 0·8	− 5·0	+ 2·4	− 0·8	− 2·9	− 0·5	+ 0·6	+ 2·2	− 0·3	+ 0·5	+ 0·6	− 0·4	+ 3·3	+ 0·4	+ 6·9	− 0·5	− 3·8	+ 4·5	+ 0·6	− 2·9
e	+ 18·6	+ 6·3	− 2·1	+ 7·8	+ 2·1	− 2·8	+ 3·8	− 1·3	− 5·4	− 2·9	− 0·7	+ 4·0	− 0·3	+ 0·3	+ 0·9	− 0·7	− 1·1	− 0·6	+ 11·4	− 3·4	− 0·6	+ 5·2	− 1·8	− 1·3
s	+ 21·3	+ 7·6	− 2·7	+ 18·4	+ 1·5	− 1·9	+ 0·3	− 1·6	− 7·4	− 6·7	− 1·6	+ 5·2	− 0·3	0·0	+ 0·1	− 0·3	− 1·3	+ 4·9	+ 19·0	− 3·4	− 2·9	+ 9·9	− 3·1	− 3·7
y	+ 19·5	+ 4·5	− 4·0	+ 12·3	+ 0·9	− 3·3	+ 2·2	− 1·2	− 5·2	− 3·4	− 0·6	+ 3·8	− 0·3	+ 0·3	+ 0·5	− 0·5	+ 0·3	+ 1·6	+ 12·4	− 2·4	− 2·4	+ 6·5	− 1·4	− 2·6
	Disturbed Days.																							
w	+ 100·7	+ 31·8	+ 22·0	− 16·0	− 11·6	+ 4·4	− 5·9	− 5·9	− 12·6	− 12·4	+ 1·8	+ 13·9	− 0·7	− 4·6	+ 1·0	− 1·1	− 64·5	− 29·4	+ 57·8	− 1·8	− 11·1	+ 5·1	− 9·3	− 1·5
e	+ 117·4	+ 8·7	+ 23·3	− 13·1	− 1·5	+ 1·7	− 7·6	+ 13·6	− 17·4	− 16·2	+ 4·1	+ 12·2	− 0·7	+ 0·2	− 2·0	− 4·1	− 104·7	− 34·5	+ 59·0	− 14·1	− 3·8	+ 2·0	− 1·7	− 2·9
s	+ 104·2	+ 4·3	+ 36·4	− 10·2	− 15·1	+ 18·7	+ 13·2	− 10·9	− 13·4	− 23·2	− 1·1	+ 12·8	+ 3·6	− 0·6	− 1·5	− 3·4	− 91·3	− 31·8	+ 38·0	− 13·6	+ 14·4	− 22·6	− 5·7	+ 12·7
y	+ 107·4	+ 14·9	+ 27·2	− 13·1	− 9·4	+ 8·3	− 0·1	− 1·1	− 14·4	− 17·3	+ 1·6	+ 13·0	+ 0·7	− 1·7	− 0·8	− 2·9	− 86·8	− 31·9	+ 51·6	− 9·8	− 0·2	− 5·3	− 5·5	+ 2·8

radiating from these positions for the year show the three seasonal values. The seasonal values for the 6-hour wave are too uncertain to justify representation.

As an example of the interpretation of the harmonic dials, the left-hand part of the top compartment of fig. 12 shows that in H there is practically no change of phase, but a steady increase in amplitude from 20 γ to about 110 γ for the 24-hour component of the regular diurnal variation in passing from the quiet, through all, to disturbed days. The three seasonal positions for the same wave on disturbed days show that there is little difference in amplitude between summer and winter, but that the summer phase is advanced from 17·4h to 16·4h L.M.T.

In the following description of the characteristics of the harmonic dials, the wave in question will be denoted by a suffix to the letter H, D, or Z indicating the magnetic element. The outstanding features of the four diagrams are readily noticeable especially when considered in conjunction with Tables 44–45.

(i) *24-Hour component.*—(*a*) Except in Z the characteristics proper to *q* days differ from those of *d* days only in the scale of the amplitude. In Z, however, the *q* day phase differs completely from that for *d* days; the *q* and *d* day phases are similar only in the equinoctial months. This confirms the deduction made from the form of the inequalities that the effects of disturbance predominate in H and D even on the internationally selected *q* days, but that the diurnal variation in Z has a form even on ordinary *q* days different from that of *d* days.

(*b*) In the high latitude Antarctic stations of Cape Evans and Cape Denison the seasonal change of scale of the inequalities suggested that the current system responsible for the quiet or ordinary day diurnal variation at midsummer was similar to that which produces disturbance there in midwinter. This would be illustrated in a harmonic dial by the *s* vectors extending outwards from the centre without change of phase and conversely by the *w* vectors retreating towards the centre. This is prominently shown in D_{24} and partly in Z_{24}, but not at all for H. Indeed, in H the comparative equality in the seasonal amplitudes for all three sets of days is remarkable.

(*c*) The almost exact opposition of phase of the 24-hour components for H and Z on *d* days is unmistakable. This is a natural consequence of the current system responsible for the regular disturbance variation being consistently to the south of the station.

(ii) *12-Hour component.*—(*a*) In Z_{12} and D_{12} the effect of disturbance is to increase the amplitude but to cause little change in phase; in H_{12} both phase and amplitude alter with increasing disturbance.

(*b*) On *q* days the amplitude of 12·7 γ for Z_{12} is greater than the amplitudes of the other waves in the diurnal variation of vertical force. For Z_{24} it is 1·6 γ and for Z_8 7·0 γ. The amplitude of H_{12} on *q* days, on the other hand, is the same as for Z_{12}, but only $\frac{3}{5}$ of H_{24} on the same class of days.

On the average *d* day the phase of H_{12} is only $1\frac{1}{2}$ hours different from H_{24}, but on *q* days the difference is $2\frac{1}{2}$ hours; $4\frac{1}{2}$ hours separate the times of maxima of H_{12} in the annual mean *q* and *d* day variations.

The evidence therefore is that as the change in phase of Z_{24} pointed to a difference in type of the diurnal variations of Z on *q* and *d* days, so the phase of H_{12} points to a change in the form of the H variation with increasing disturbance.

(*c*) Independent of the magnetic character of the day, the phase angle of H_{12} is greater in *s* than in *w*. This is also true of *q* and all days in Z and D.

(*d*) Disturbance increases the amplitude of the 24-hour wave relative to the 12-hour wave in all components, as is shown in the following values of the ratio c_{24}/c_{12} for *q* and *d* days:—

	H.	D.	Z.
q . .	1·56	1·63	0·13
d . .	3·60	1·72	1·76

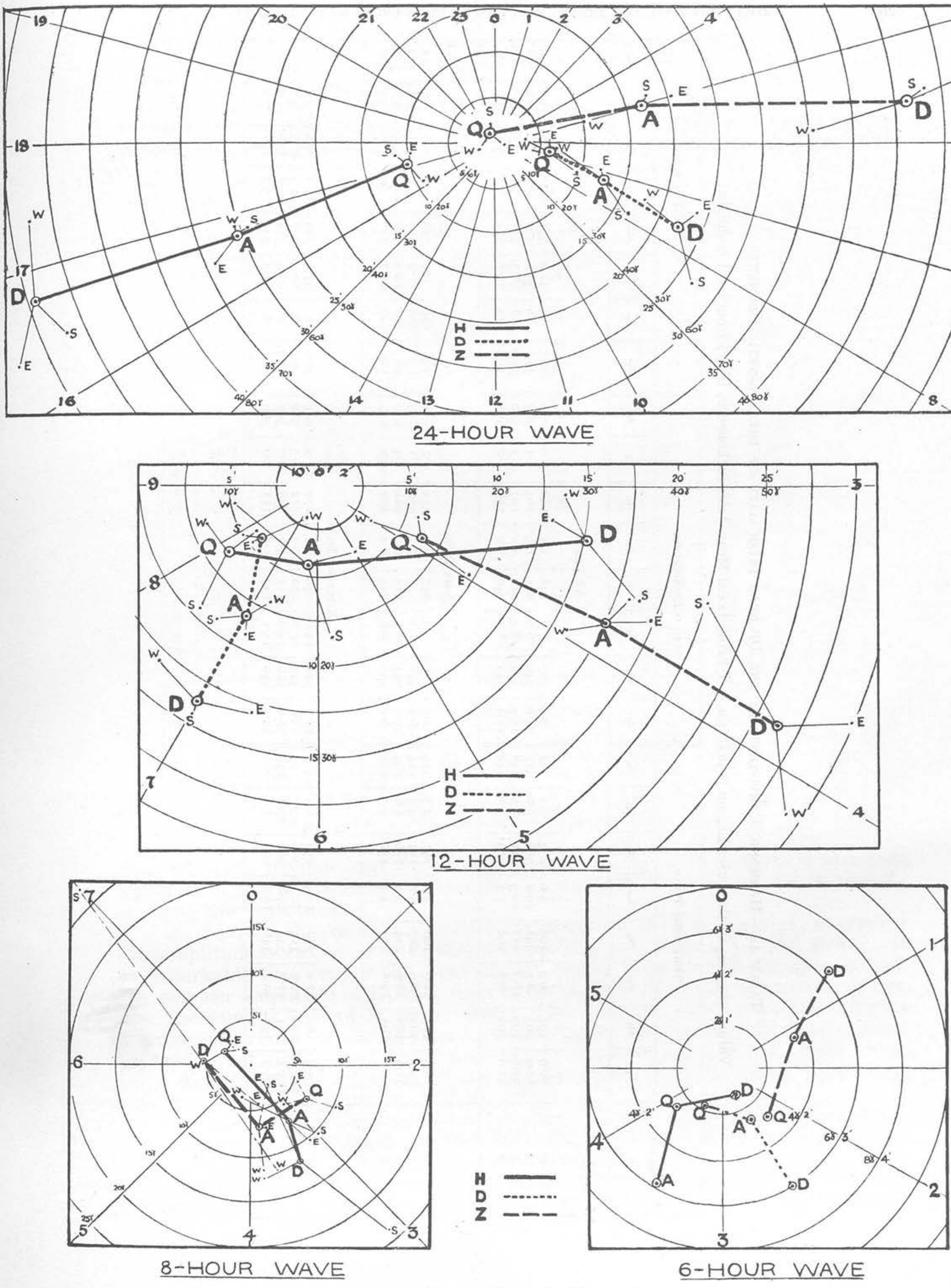


FIG. 12.—Harmonic dials.

TABLE 44.—HARMONIC COMPONENTS OF THE DIURNAL INEQUALITY OF THE MAGNETIC ELEMENTS.

Values of c_n, α_n in the series $\Sigma c_n \sin(15nT^\circ + \alpha_n)$, T being Local Mean Time reckoned in hours from local midnight.

Season.	Horizontal Force.								Declination.								Vertical Force.							
	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
												All Days.												
	γ	°	γ	°	γ	°	γ	°	′	°	′	°	′	°	′	°	γ	°	γ	°	γ	°	γ	°
w	60·9	197	9·3	190	3·6	253	5·1	252	8·9	357	7·2	248	1·7	100	0·6	228	20·1	14	32·0	331	11·8	280	3·2	299
e	67·4	203	8·7	298	10·2	306	3·8	211	13·6	349	8·6	243	0·9	164	2·1	303	40·7	16	39·6	339	6·7	286	6·2	38
s	57·8	199	16·7	272	10·3	316	8·9	248	15·3	334	8·5	230	1·2	107	1·5	320	34·6	18	36·3	341	3·1	295	4·7	43
y	62·0	200	8·8	260	7·5	303	5·8	242	12·4	345	8·1	240	1·0	159	1·2	301	31·8	16	35·8	337	7·1	284	3·6	23
												Quiet Days.												
w	18·6	207	12·7	198	5·1	177	2·5	213	2·9	17	2·3	247	0·6	313	0·7	231	3·4	199	6·9	326	5·9	308	3·0	273
e	19·6	187	8·0	217	3·5	131	4·0	214	6·1	358	4·1	222	0·4	308	1·1	233	1·3	359	11·9	339	5·3	342	2·2	339
s	22·6	186	18·6	224	2·5	130	1·6	275	10·0	344	5·5	215	0·3	261	0·3	270	5·1	101	19·3	332	10·3	332	4·8	325
y	20·0	193	12·8	214	3·4	152	2·5	224	6·2	353	3·8	223	0·4	300	0·7	239	1·6	127	12·7	333	7·0	328	3·0	313
												Disturbed Days.												
w	105·6	189	27·2	358	12·4	279	8·4	330	17·7	342	14·0	240	4·7	177	1·5	243	70·9	2	57·9	324	12·2	283	9·4	5
e	117·7	202	26·7	352	2·3	306	15·6	75	23·8	343	12·9	250	0·7	272	4·5	310	110·2	8	60·7	336	4·3	285	3·4	314
s	104·3	204	37·7	338	24·0	309	17·1	234	26·7	326	12·9	227	3·7	88	3·7	307	96·7	7	40·4	342	26·8	136	13·9	80
y	108·5	198	30·1	348	12·5	299	1·1	292	22·5	336	13·1	239	1·8	145	3·0	300	92·5	6	52·5	333	5·3	170	6·2	41

(*e*) Unlike the 24-hour wave whose phases in H and Z are in opposition on both *q* and *d* days, the phases of H_{12} and Z_{12} are related to each other only in that the phase of H_{12} on *d* days is within one hour of Z_{12} on days of all classes.

(iii) *8-Hour wave.*—No rigorous conclusions may be drawn about this constituent of the diurnal variation from 13 months' data. But in view of its value in dealing with that part of the diurnal variation left unaccounted for at times of the

TABLE 45.—HOURS OF MAXIMA OF HARMONIC COMPONENTS REFERRED TO LOCAL MEAN MIDNIGHT, FOR ALL, *q*, AND *d* DAY INEQUALITIES.

	H.				D.				Z.			
	α_1.	α_2.	α_3.	α_4.	α_1.	α_2.	α_3.	α_4.	α_1.	α_2.	α_3.	α_4.
					All Days.							
	h	h	h	h	h	h	h	h	h	h	h	h
w	16·8	8·7	4·4	3·3	6·3	6·7	7·8	3·7	5·0	4·0	3·8	2·5
e	16·5	5·1	3·2	4·0	6·7	6·9	6·3	2·4	4·9	3·7	3·6	0·8
s	16·7	5·9	3·0	3·4	7·7	7·3	7·6	2·2	4·8	3·7	3·4	0·8
y	16·6	6·3	3·3	3·5	7·0	7·0	6·5	2·5	4·9	3·8	3·7	1·1
					Quiet Days.							
w	16·2	8·4	6·1	4·0	4·9	6·7	3·0	3·6	16·7	4·1	3·1	3·0
e	17·5	7·7	7·1	3·9	6·1	7·6	3·2	3·6	6·1	3·7	2·4	1·9
s	17·6	7·5	7·1	2·9	7·1	7·8	4·2	3·0	23·3	4·0	2·6	2·1
y	17·1	7·8	6·6	3·8	6·5	7·6	3·3	3·5	21·5	3·9	2·7	2·3
					Disturbed Days.							
w	17·4	3·1	3·8	2·0	7·2	7·0	6·0	3·5	5·9	4·2	3·7	1·4
e	16·5	3·3	3·2	0·2	7·1	6·6	4·0	2·3	5·5	3·8	3·7	2·3
s	16·4	3·7	3·1	3·6	8·2	7·4	0·0	2·4	5·5	3·6	7·0	0·1
y	16·8	3·4	3·4	2·6	7·6	7·0	6·8	2·5	5·6	3·9	6·2	0·8

year when the daylight and dark hours are more nearly in the ratio of 2 to 1 than equal, it is instructive briefly to examine its seasonal changes, and for H_8 and Z_8, at least, this is justified.

On *d* days in the equinoctial months the amplitude of H_8 is only 2·3 γ, in summer the amplitude is 24·0 γ. For Z_8 the corresponding values are 4·3 γ and 26·8 γ. It is remarkable that neither the *q* nor all day values show similar changes; indeed, the summer amplitude of H_8 on *q* days is the smallest of the three seasonal values, and the same is true of Z_8 on all days. This probably arises from the different relative importance of the 24- and 12-hourly waves and their variability in phase on both *q* and all days, compared with the steadiness of phase of both these waves on *d* days and their relatively greater predominance over the other constituent waves of the diurnal variation on those *d* days.

(iv) *6-Hour wave.*—Though the amplitudes of Z_6 and D_6 derived from the annual mean variation on *d* days are greater than the amplitudes of Z_8 and D_8, there is little to be gained by a detailed examination of the seasonal amplitudes or phases of the 6-hour wave. The changes of phase are too great and uncertain for the results to have significance. Probably the only consistent feature in the 6-hourly harmonic dial is that the all day positions in Z and D lie between those representing *q* and *d* days. This suggests that increasing disturbance systematically affects both the amplitude and phase of the 6-hour wave.

§ 62. *Harmonic analysis of mean inequalities for selected quietest and most disturbed days.*—The annual and seasonal mean inequalities (Table 230 of Vol. II) for the 38 quietest *q′* and 40 most disturbed *d′* days have been analysed harmonically in the same way as the inequalities for all and for ordinary *q* and *d* days. The results are given in Tables 46, 47, and 48. In view of the differences in the characteristics of the regular diurnal variations of H and Z on *q* and *d* days, primary interest naturally attaches to any further differences brought to light by the group of *q′* days. Comparison of the amplitudes and phase angles for the *q* and *q′* days in Tables 44 and 47 leads to the following conclusions:—

(i) *24-Hourly wave.*—On the average of the year the time of maximum of H_{24} on *q′* days is 2½ hours later than on *q* days. This phase change is common to all seasons, but is greatest in summer. The *q′* amplitudes are less than for *q* days, except in summer when they are about equal.

In Z the amplitudes of the 24-hour wave are so small in all seasons that changes of phase angle have no significance, and for D_{24} both the amplitudes and phases are surprisingly similar in *q* and *q′* days in all seasons.

(ii) *12-Hourly wave.*—The phase of H_{12} on *q′* days is not consistently different from that of *q* days, but the *q* amplitudes are generally at least double those of *q′* days. In Z_{12} the phase change is small, and the *q′* amplitudes are about two-thirds those of *q* days, while in D the amplitudes are practically the same on both classes of days, but the maximum of D_{12} is at least 0·3 hours later on *q′* than on *q* days in all seasons.

Thus the evidence of the two more important harmonic constituents of the daily variation confirm the deductions of earlier paragraphs, that so far (magnetically) north as Fort Rae a regular diurnal variation different in type from that of disturbed days dominates the changes in field on the quietest days. But this regular quiet-day variation is so small compared with that peculiar to disturbed days and so continuously masked by residual slight disturbance, that its characteristics are only discernible on a very limited number of days during the quietest periods, and then only when both the whole and semi-diurnal components of the variation are examined. Even on the very quietest days the form of the daily variation of the field transverse to the meridian is substantially the same as on the average disturbed day.

The effect on the characteristics of the harmonic waves of segregating the most disturbed from the average disturbed days varies with the element of the field. In H and Z the 12-hour wave remains practically the same in both amplitude and phase; almost the entire effect is concentrated in the 24-hour wave. The amplitude of H_{24} is increased by 23% from *d* to *d′* days and that of Z_{24} by 30%. In addition, whereas the phase of Z_{24} is unaffected, an increase of the degree of disturbance involves an advance of the time of maximum in H_{24}, the difference between the *d* and *d′* classes being an hour in all seasons. Increased disturbance has no substantial effect on D. For *d′* days the phase angle of D_{24} in all seasons differs at most by 2° from the angle on *d* days, and the phase of D_{12} is almost equally steady.

§ 63. *The absolute daily range* (R).—Arranged with the 13 sets, each of three tables, showing for each month the hourly mean values of the primary elements H, D, and Z (see *e.g.* Tables 160, 161, and 162 of Vol. II for August 1932), a fourth table in each set (*e.g.* Table 163 of Vol. II) supplies details of the times of incidence of the instantaneous maximum and minimum values and the values of the components at these times. The difference between the maximum and minimum instantaneous values in each day—the absolute or extreme range—will be denoted by R and average value of R by $\bar{R}$. Values of R are complete for all days of the 13 months except for one day each in H and D (April 4 and April 2 respectively)

TABLE 46.—VALUES OF THE CONSTANTS a, b, IN THE HARMONIC ANALYSIS OF q' AND d' INEQUALITIES
(t being reckoned in hours from midnight Greenwich Mean Time).

	Horizontal Force.								Declination.								Vertical Force.							
	a_1.	b_1.	a_2.	b_2.	a_3.	b_3.	a_4.	b_4.	a_1.	b_1.	a_2.	b_2.	a_3.	b_3.	a_4.	b_4.	a_1.	b_1.	a_2.	b_2.	a_3.	b_3.	a_4.	b_4.
	Quietest Days.																							
	γ	γ	γ	γ	γ	γ	γ	γ	′	′	′	′	′	′	′	′	γ	γ	γ	γ	γ	γ	γ	γ
w	10·4	7·5	-5·8	0·7	3·0	0·3	-0·4	-1·4	-2·4	-0·7	0·0$_4$	2·3	0·3	-0·2	0·2	0·4	4·1	1·9	4·7	-0·7	-1·5	1·0	0·5	-0·0$_3$
e	8·9	11·3	1·5	3·9	0·0$_1$	-3·0	1·2	0·0$_5$	-4·7	-2·4	-1·1	3·1	0·7	0·8	0·2	-0·4	3·9	2·4	6·9	-1·7	0·4	1·2	0·4	0·6
s	8·1	20·5	2·2	8·0	6·1	-1·3	1·1	2·2	-7·1	-5·8	-2·4	4·7	0·6	0·2	0·1	-0·2	2·3	7·6	12·3	2·2	-2·5	2·6	0·3	-0·7
y	9·1	13·1	-0·7	4·2	3·0	-1·3	0·6	0·3	-4·7	-3·0	-1·1	3·4	0·5	0·3	0·2	-0·1	3·4	3·9	8·0	-0·1	-1·2	1·6	0·4	-0·0$_5$
	Most Disturbed Days.																							
w	136·5	12·5	25·3	-9·5	-5·3	-17·1	-4·9	-0·7	-149·2	-139·3	13·9	138·0	-20·8	-50·3	11·8	-17·2	-99·6	-51·7	59·8	-10·4	1·2	12·5	-12·6	-0·9
e	138·5	-24·5	30·2	-3·7	-14·4	1·3	-0·3	15·9	-156·0	-155·3	27·7	132·2	-0·8	-6·1	-9·8	-62·9	-36·8	-25·7	66·2	-25·9	-6·3	8·5	-11·3	-7·3
s	135·0	-22·5	37·7	-0·8	-19·3	10·4	20·9	-20·9	-130·1	-217·9	-9·3	160·9	3·0	11·5	4·8	-44·0	-119·0	-46·7	29·4	-22·0	25·8	-12·6	-11·4	14·1
y	136·7	-11·5	31·0	-4·8	-13·1	-1·7	5·2	-1·9	-145·2	-170·8	10·7	143·8	-6·2	-15·0	2·2	-41·5	-112·9	-41·3	51·6	-19·5	6·9	2·9	-11·9	2·0

TABLE 47.—VALUES OF THE CONSTANTS c, α IN THE ALTERNATIVE FORM OF ANALYSIS OF q' AND d' INEQUALITIES
(T being Local Mean Time reckoned in hours from local midnight).

	Horizontal Force.								Declination.								Vertical Force.							
	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
	Quietest Days.																							
	γ	°	γ	°	γ	°	γ	°	′	°	′	°	′	°	′	°	γ	°	γ	°	γ	°	γ	°
w	25·5	170	5·9	149	3·0	72	1·5	301	2·5	9	2·3	233	0·3	109	0·4	136	4·5	181	4·7	331	1·8	292	0·5	191
e	14·3	155	4·1	253	3·0	168	1·2	192	5·2	359	3·3	213	1·1	28	0·5	261	4·5	150	7·1	336	1·3	5	0·7	137
s	22·0	137	8·3	248	6·2	91	2·4	130	9·2	347	5·3	205	0·7	61	0·3	259	7·9	133	12·5	312	3·6	305	0·8	262
y	15·9	151	4·2	223	3·3	102	0·7	170	5·6	354	3·6	213	0·6	50	0·2	220	5·2	161	8·0	323	2·0	311	0·4	201
	Most Disturbed Days.																							
w	137·1	201	27·0	343	17·9	185	4·9	6	20·4	343	13·9	238	5·4	191	2·1	250	112·2	359	60·7	332	12·6	354	12·6	10
e	140·7	216	30·4	329	14·5	263	15·9	103	22·0	341	13·5	244	0·6	176	6·4	293	44·9	351	71·1	343	10·6	312	13·5	341
s	136·9	215	37·7	323	21·9	287	29·6	239	25·4	327	16·1	229	1·2	3	4·4	278	127·8	5	36·7	359	28·7	104	18·1	65
y	137·2	211	31·4	331	13·2	251	5·5	215	22·4	337	14·4	236	1·6	191	4·2	281	120·2	6	55·2	343	7·5	55	12·1	24

and four days in Z (April 1–4) when the magnetograms were accidentally fogged before development. It is believed that those days were neither unusually quiet nor unusually disturbed, so that the loss probably does not affect the discussion in any important respect.

TABLE 48.—HOURS OF MAXIMA OF HARMONIC COMPONENTS REFERRED TO LOCAL MEAN MIDNIGHT FOR q' AND d' DAYS.

	H.				D.				Z.			
	a_1.	a_2.	a_3.	a_4.	a_1.	a_2.	a_3.	a_4.	a_1.	a_2.	a_3.	a_4.
	Quietest Days.											
	h	h	h	h	h	h	h	h	h	h	h	h
w	18·6	10·0	0·4	2·5	5·4	7·2	7·6	5·2	17·9	4·0	3·5	4·3
e	19·7	6·5	6·2	4·3	6·1	7·9	1·4	3·1	20·0	3·8	1·9	5·2
s	20·8	6·7	8·0	5·3	6·9	8·1	0·6	3·2	21·1	4·6	3·2	3·1
y	19·9	7·5	7·7	4·7	6·4	7·9	0·9	3·8	19·2	4·3	3·1	4·1
	Most Disturbed Days.											
w	16·6	3·6	5·9	1·4	7·1	7·0	5·8	3·3	6·1	4·0	2·1	1·3
e	15·6	4·0	4·1	5·8	7·3	6·8	6·1	2·6	6·6	3·6	3·1	1·8
s	15·6	4·2	3·6	3·5	8·2	7·3	1·9	2·9	5·7	3·0	7·7	0·4
y	15·9	4·0	4·4	3·9	7·6	7·1	5·7	2·8	5·6	3·6	0·7	1·1

Table 49 gives the extreme values of the three elements attained throughout the 13 months and the dates of occurrence of these extremes. In the force elements the extremes were reached in the summer months; in D in the equinoctial months. The over-all range in H (1916 γ) is 25% of the average value of the horizontal field at Fort Rae (7734 γ); in declination the extremes for the year give a range of 9·78°, representing 1321 γ in terms of force units transverse to the mean meridian.

TABLE 49.—EXTREME VALUES: H, D, AND Z.

Component.	Maximum.		Minimum.		Absolute Range.
	Value.	Date.	Value.	Date.	
H	8070 γ	1933 Aug. 5	6154 γ	1932 Aug. 28	1916 γ
D	42° 24·0′	1932 Oct. 15	32° 37·2′	1932 Sept. 20	9° 46·8′ (= 1321 γ)
Z	60840 γ	1933 Aug. 5	58821 γ	1933 June 13	2019 γ

Table 50 summarises the monthly mean values of R for each component; it gives also the equivalent force range for D and the percentages of each monthly value of the mean of the year. The greatest and least daily range in each month extracted from Table 163 of Vol. II *et seq.* are also shown. The annual mean value of R in the last line of Table 50 is the average of the 13 months; the entries for *s* (summer) are derived by taking the mean of the two August values along with the other three summer months of 1933. In those seasonal and annual lines of the table, under the column headings "Greatest" and "Least," are entered the greatest and least of the entries for those months which comprise the seasons in question.

TABLE 50.—ABSOLUTE DAILY RANGE: MONTHLY MEAN VALUES.

Month and Season.	1932–33.															1882–83.		
	Horizontal Force.			Declination.						Vertical Force.			Mean Daily Range. Expressed as Percentage of Year's Mean.			Mean Daily Range.		
				Angle.			Equivalent Force.											
	Mean.	Greatest.	Least.	Mean.	Greatest.	Least.	Mean.	Greatest.	Least.	Mean.	Greatest.	Least.	H.	D.	Z.	H.	D.	Z.
	γ	γ	γ	′	′	′	γ	γ	γ	γ	γ	γ				γ	′	γ
1932 Aug.	593	1852	135	157·9	422·0	26·5	355	949	596	478	1066	64	117	116	106			
Sept.	579	1261	85	163·2	440·0	25·5	367	989	574	544	1178	79	114	120	121	350	66·6	232
Oct.	460	1103	81	147·5	397·1	23·0	332	893	518	460	1107	40	91	109	102	427	104·9	313
Nov.	444	1157	48	122·9	412·0	23·2	277	927	522	396	1056	19	88	91	88	613	178·1	393
Dec.	504	1409	97	124·8	335·1	29·3	281	754	660	414	1043	129	100	92	92	368	99·7	322
1933 Jan.	444	922	59	125·1	285·9	16·5	282	644	371	384	832	40	88	92	85	344	90·5	256
Feb.	493	1109	30	108·8	291·6	16·5	245	656	371	436	1120	34	97	80	97	492	129·5	356
Mar.	501	1207	101	143·5	325·4	21·9	323	732	493	492	1350	80	99	106	109	427	120·7	373
Apr.	570	1287	167	158·3	386·4	27·3	356	870	614	505	1138	86	113	117	112	323	94·2	275
May	521	1425	62	132·5	325·0	26·7	298	731	601	443	1188	66	103	98	98	366	95·7	263
June	469	981	122	118·7	284·0	37·7	267	639	848	460	1250	88	93	88	102	476	115·0	349
July	475	1375	132	115·6	329·5	37·0	260	742	833	395	980	140	94	85	88	485	123·7	393
Aug.	527	1235	97	143·1	425·8	24·5	322	958	552	450	1290	56	104	106	100	280	74·1	236
w	471	1409	30	120·4	412·0	16·5	271	927	371	407	1120	19	93	89	91	382	96·6	299
e	527	1287	81	153·1	440·0	21·9	345	989	493	500	1350	40	104	113	111	454	124·5	332
s	506	1852	135	129·3	425·8	24·5	291	958	552	441	1290	56	102	95	98	402	102·1	310
y	506	1852	30	135·6	440·0	16·5	305	989	371	451	1350	19	..	..	..	413	107·7	313

Considering the relatively low magnetic activity of the months represented in Table 50, the consistently high values of $\bar{R}$ in all three components is remarkable. Only 2 of the 13 months were without days of R in H or Z greater than 1000 γ; in D a day with R greater than $4\frac{1}{2}°$ occurred in every month. Nor were the greatest ranges confined to the equinoctial months. During both winter and summer, individual days occurred with R_H conspicuously greater than in the equinoctial months. In D, days with R approximately 7° occurred in all three seasons, and in Z, though the greatest R value (1350 γ) occurred in March, it exceeded by only 60 γ the next greatest in August 1933 near the minimum of the solar cycle of activity.

For the entire 13 months the values of $\bar{R}_H$, $\bar{R}_D$, and $\bar{R}_Z$ were 506 γ, 305 γ, and 451 γ respectively. These are approximately in the ratio of 10 : 6 : 9. The ratio of the ranges in H and Z remains fairly constant throughout the year, but is smaller in the equinoctial months than in winter or summer, as the seasonal values of the ratio in Table 51 show.

In such a latitude as Fort Rae and at a time so near the minimum of the cycle of solar activity it might have been expected that R would have been vanishingly small in winter. Actually November and February were the only months with days of R_H less than 50 γ. One day in November had an R_Z of 19 γ, but in addition to this month only October, January, and February had minimum values of R_Z less than 40 γ. That this was not alone due to the incidence of small perturbations on the quietest days keeping R high has already been seen in discussing the inequalities from the q' group of days. The range of the mean inequality on these quietest days in winter was 39 γ in H and 16 γ in Z.

The section of Table 50 which shows the percentage each monthly $\bar{R}$ bears to the mean for the year emphasises the similarity among the months for prevalence of large ranges. In all three elements the percentage is lowest in winter and highest in the equinoctial months.

TABLE 51.—SEASONAL VALUES OF $\bar{R}_H/\bar{R}_Z$.

Fort Rae.	$\bar{R}_H/\bar{R}_Z$.			
	y.	*w.*	*e.*	*s.*
All days	1·12	1·16	1·05	1·15
Days of greatest R in each month . .	1·37	1·26	0·95	1·44

§ 64. *Comparison with 1882–83 ranges.*—As explained earlier (§ 59), the only approximation to R provided by the 1882–83 data is the range derived from the difference between the greatest and least of the instantaneous hourly readings during each day. The monthly mean values of this quantity are given in the extreme right-hand compartment of Table 50. For the year the average values are 413 γ for H, 107·7′ for D, and 313 γ for Z, these being respectively 82%, 79%, and 70% of $\bar{R}_H$, $\bar{R}_D$, and $\bar{R}_Z$ in 1932–33. From these results we deduce that the mode of obtaining the range from the 1882–83 data, in its tendency consistently to diminish extreme values, more than outweighs the great difference in magnetic activity between the two years, and this in a manner which varies with the characteristics of the movements in disturbance as recorded in the several components.

The only safe conclusion from the 1882–83 data is that in that year the greatest ranges occurred in the equinoctial months, and the least ranges in the winter months, but, as in 1932–33, the difference between the seasons was not very conspicuous.

TABLE 52.—SEASONAL VALUES OF $\bar{R}_H$, $\bar{R}_D$, AND $\bar{R}_Z$ AT TROMSÖ AND LERWICK, 1932–33, AND THEIR RATIOS.

	Tromsö.			Lerwick.			$\bar{\bar{R}}$.			$\bar{\bar{R}}_{F.R.}/\bar{\bar{R}}_{Tromsö}$.	$\bar{\bar{R}}_{F.R.}/\bar{\bar{R}}_{Ler}$.
	$\bar{R}_H$.	$\bar{R}_D$.	$\bar{R}'_Z$.	$\bar{R}_H$.	$\bar{R}_D$.	$\bar{R}_Z$.	F. Rae.	Tromsö.	Lerwick.		
	γ	γ	γ	γ	γ	γ	γ	γ	γ		
w	369	184	230	68	77	80	383	261	75	1·5	5·1
e	517	231	287	101	89	111	457	345	100	1·3	4·6
s	385	178	242	115	82	97	413	268	98	1·5	4·2
y	421	196	252	96	83	96	421	290	92	1·5	4·6

§ 65. *Comparison with* $\bar{R}$ *at other stations.*—To convey some idea of the scale of the daily changes in the magnetic elements at Fort Rae, the average absolute ranges at Tromsö and Lerwick are given in Table 52 for the same three elements and covering the same 13 months. Judged by moderate latitude standards, Lerwick is already a very highly disturbed station. But whereas the average range for all elements for the 13 months ($\bar{\bar{R}}$) was 421 γ at Fort Rae, it was 290 γ

at Tromsö and only 92 γ at Lerwick. On this criterion Fort Rae is 1·5 times as disturbed as Tromsö and 4·6 times as disturbed as Lerwick. As has been demonstrated elsewhere (§ 54), there is a seasonal shift in the zone of maximum concentration of disturbance. This is partly demonstrated by Table 52. Relative to Lerwick, Fort Rae is more disturbed in winter (5·1) than in summer (4·2), the difference being most accentuated in the horizontal component. In November and December 1932 $\bar{R}_H$ at Fort Rae was 474 γ, but at Lerwick only 48 γ, a ratio of almost 10 : 1.

Throughout the year the greater all-round disturbance at Fort Rae compared with Tromsö is most marked in the vertical component of the field and least in the horizontal component. For the 13 months $\bar{R}_{F.R.}/\bar{R}_{Tromsö}$ is 1·2 for H, 1·6 for D, and 1·8 for Z, the ratios being almost constant in all seasons.

§ 66. *Relation of disturbance to magnetic latitude.*—The great increase in the scale of disturbance between Lerwick and Fort Rae has been investigated in detail and extended to include localities ranging from 11° south of the magnetic equator to within 2° of the magnetic axis pole. The results of this inquiry have been published elsewhere.* Here it need only be said that if the range product $HR_H + ZR_Z$ (*cf.* § 71) can be regarded as an adequate (relative) criterion of magnetic disturbance in different localities, then the zone of greatest average disturbance probably passes through magnetic latitude (Φ_m) 72°, just to the north of Fort Rae, so that the zone of highest disturbance concentration lies just inside the Fritz line of maximum auroral frequency. Approaching this zone from the south, the scale of disturbance increases steadily from $\Phi_m = 50°$ to 60°, then very steeply from 60° to 70°; the fall away towards the magnetic axis pole is less steep, so that in the neighbourhood of the pole, disturbance on the average is about the same as at $\Phi_m = 60°$.

§ 67. *Frequency distribution of* R.—Tables 53 to 56 show for each month and each component the frequency distributions of R, the entries being the number of days in each month when R reached the limits specified in the column headings. For D expressed in units of force transverse to the meridian the intervals are the same as for H and Z (50 γ); for D expressed in angular measure the interval is 20′.

The primary features common to all four tables are:

(i) The great scatter in possible values of R throughout the year;

(ii) The absence of any nodes in the frequency distribution; and

(iii) The small differences among the months in liability to occurrences of great ranges.

These features are more readily illustrated by Tables 57 and 58 where the monthly data of Tables 53 to 56 are grouped into seasons and combined into one distribution. In the double (100 γ) interval with limits from 450 γ to 550 γ and so comprising the mean $\bar{R}_H$ (506 γ), only 12·1% of all H ranges occur. To include only 63% of all values of R_H recorded in 1932–33 the interval must be extended from 100 γ (450–550 γ) to 550 γ (100–650 γ), and no one of the eleven 50 γ sub-intervals in this range has more than 9% or less than 5% of the total number. The same feature is prominent in D and Z. Except to a minor degree in summer when the number of R_D in the interval 100–149 γ is 16·9% of the total, none of the distributions have any real concentrations of frequency round a node.

The expectancy of great ranges varies with season in a similar manner in all components, but in each component the seasonal differences are small. For ranges above 1000 γ the percentage number of occurrences in H and Z are as follows:

	Winter.	Equinox.	Summer.
H	6·5	9·1	7·1
Z	2·4	5·0	4·0

* *Terr. Mag.*, **40**, pt. 3, pp. 255–262 (1935).

TABLE 53.—MONTHLY FREQUENCY DISTRIBUTION OF ABSOLUTE DAILY RANGE: HORIZONTAL FORCE.

Month.	0 γ to 49 γ	50 γ to 99 γ	100 γ to 149 γ	150 γ to 199 γ	200 γ to 249 γ	250 γ to 299 γ	300 γ to 349 γ	350 γ to 399 γ	400 γ to 449 γ	450 γ to 499 γ	500 γ to 549 γ	550 γ to 599 γ	600 γ to 649 γ	650 γ to 699 γ	700 γ to 749 γ	750 γ to 799 γ	800 γ to 849 γ	850 γ to 899 γ	900 γ to 949 γ	950 γ to 999 γ	1000 γ to 1049 γ	1050 γ to 1099 γ	1100 γ to 1149 γ	1150 γ to 1199 γ	1200 γ to 1249 γ	1250 γ to 1299 γ	⩾1300 γ
1932 Aug.	..	..	1	3	6	..	3	..	1	2	..	2	1	3	..	1	2	1	..	1	..	..	..	1	..	..	3 (1381, 1563, 1852)
Sept.	..	1	2	3	..	1	2	1	1	..	4	2	..	1	3	2	2	1	..	1	1	..	..	..	..	1	1 (1301)
Oct.	..	3	3	1	3	2	2	..	2	1	2	1	2	3	1	..	2	1	..	..	..	1	1				
Nov.	1	1	2	2	..	2	1	3	5	4	2	2	1	1	..	..	1	..	..	..	..	..	1	1			
Dec.	..	1	..	1	2	4	1	5	3	2	2	5	1	..	1	..	..	..	..	..	..	..	..	..	1	1	1 (1409)
1933 Jan.	..	4	3	1	..	2	2	..	3	1	3	1	5	1	1	2	..	1	1								
Feb.	1	1	2	3	3	1	2	1	..	2	..	4	..	..	..	..	1	3	1	..	1	1	1				
Mar.	..	..	4	2	1	2	2	..	4	2	1	2	4	..	1	1	1	1	..	1	1	..	..	..	1		
Apr.	..	..	..	1	2	2	3	4	2	2	1	1	2	1	2	..	1	..	..	1	1	..	..	2	..	1	
May	..	1	..	1	1	7	1	2	3	..	2	3	..	2	1	1	2	..	2	..	1	..	..	..	..	..	1 (1425)
June	..	..	1	2	..	7	1	2	3	2	3	1	1	1	2	1	1	..	1	1							
July	..	..	1	1	3	3	2	4	3	5	1	..	3	..	1	1	1	..	..	..	..	1	..	..	..	..	1 (1375)
Aug.	..	1	4	3	1	1	2	1	1	4	..	..	..	2	1	3	..	2	..	2	1	1	..	..	1		

TABLE 54.—MONTHLY FREQUENCY DISTRIBUTION OF ABSOLUTE DAILY RANGE: VERTICAL FORCE.

Month.	0 γ to 49 γ	50 γ to 99 γ	100 γ to 149 γ	150 γ to 199 γ	200 γ to 249 γ	250 γ to 299 γ	300 γ to 349 γ	350 γ to 399 γ	400 γ to 449 γ	450 γ to 499 γ	500 γ to 549 γ	550 γ to 599 γ	600 γ to 649 γ	650 γ to 699 γ	700 γ to 749 γ	750 γ to 799 γ	800 γ to 849 γ	850 γ to 899 γ	900 γ to 949 γ	950 γ to 999 γ	1000 γ to 1049 γ	1050 γ to 1099 γ	1100 γ to 1149 γ	1150 γ to 1199 γ	1200 γ to 1249 γ	1250 γ to 1299 γ	⩾1300 γ
1932 Aug.	..	2	1	4	3	3	1	2	..	3	1	1	..	1	1	1	1	3	..	1	..	2					
Sept.	..	2	1	3	..	..	4	..	2	2	3	..	1	3	2	1	1	1	1	1	..	..	..	2			
Oct.	1	4	..	3	2	3	1	2	..	1	2	2	1	1	1	2	1	..	1	2	1	..	1				
Nov.	1	3	1	1	..	3	5	3	..	2	5	1	2	1	1	..	..	..	..	..	..	1					
Dec.	..	..	1	3	2	4	4	2	6	3	1	1	..	1	..	..	1	1	..	..	1						
1933 Jan.	1	3	4	2	3	..	1	1	..	1	6	3	2	1	2	..	1										
Feb.	1	4	2	2	..	1	5	2	..	..	1	2	1	..	1	1	1	..	2	1	..	..	1				
Mar.	..	2	2	3	..	2	2	3	3	2	..	..	3	2	1	1	2	..	..	1	1	..	..	..	..	..	1 (1350)
Apr.	..	1	1	1	..	1	5	4	2	2	..	..	..	..	1	3	2	1	1	..	..	..	1				
May	..	1	2	1	2	3	3	3	4	2	3	..	1	1	..	3	..	1	..	..	..	..	..	1			
June	..	1	..	3	1	4	4	2	1	2	3	3	1	2	..	..	1	..	..	..	..	..	1	..	..	1	
July	..	..	3	1	4	3	4	3	2	4	1	2	2	..	..	..	1	..	..	1							
Aug.	..	5	3	1	1	2	1	3	2	..	..	1	1	2	4	2	1	1	..	..	..	..	..	..	..	1	

If these numbers are significant, large ranges are most likely to occur in the equinoctial months and more likely in summer than in winter.

At the other end of the scale, absolute ranges below 50 γ in H and Z and even in D in the summer and equinoctial months are very rare. Judging by Tables 57 and 58, R is likely to be below 50 γ on only five days in H, fifteen days in D, and twelve days in Z in every thousand days. In years nearer the maximum of the sunspot cycle such low values of R will be even less frequent. In comparison

TABLE 55.—MONTHLY FREQUENCY DISTRIBUTION OF ABSOLUTE DAILY RANGE: DECLINATION.

(In angular measure.)

Month.	0° to 1°.			1° to 2°.			2° to 3°.			3° to 4°.			4° to 5°.			5° to 6°.			
	0′ to 19′.	20′ to 39′.	40′ to 59′.	60′ to 79′.	80′ to 99′.	100′ to 119′.	120′ to 139′.	140′ to 159′.	160′ to 179′.	180′ to 199′.	200′ to 219′.	220′ to 239′.	240′ to 259′.	260′ to 279′.	280′ to 299′.	300′ to 319′.	320′ to 339′.	340′ to 359′.	> 6°.
1932 Aug.	..	4	5	1	2	4	..	..	2	2	2	1	2	..	1	2	2	..	1(422·0′)
Sept.	..	4	2	2	..	3	3	3	1	3	1	3	2	..	..	..	..	..	3(367·3′, 430·3′, 440·0′)
Oct.	..	5	5	..	1	2	4	2	2	..	1	2	2	1	1	1	1	..	1(397·1′)
Nov.	..	4	3	2	3	2	5	4	3	2	..	1	..	..	..	..	..	..	1(412·0′)
Dec.	..	2	4	4	6	1	4	4	1	1	..	1	..	..	2	..	1		
1933 Jan.	3	4	4	1	..	1	1	4	4	3	4	..	1	..	1				
Feb.	2	4	4	3	2	2	2	2	1	1	3	..	1	..	1				
Mar.	..	2	6	1	2	4	2	4	1	1	1	..	1	2	2	1	1		
Apr.	..	1	2	2	5	3	1	4	1	2	2	1	..	2	..	..	1	1	1(386·4′)
May	..	2	3	5	2	5	2	4	..	3	..	..	2	1	..	1	1		
June	..	1	4	5	3	3	2	8	1	..	..	2	..	..	1				
July	..	1	6	4	5	2	4	2	2	3	..	..	1	..	..	..	1		
Aug.	..	6	3	3	1	3	2	..	1	2	2	2	3	..	..	2	..	..	1(425·8′)

TABLE 56.—MONTHLY FREQUENCY DISTRIBUTION OF ABSOLUTE DAILY RANGE: DECLINATION.

(In equivalent force units perpendicular to the meridian.)

Month.	0 γ to 49 γ.	50 γ to 99 γ.	100 γ to 149 γ.	150 γ to 199 γ.	200 γ to 249 γ.	250 γ to 299 γ.	300 γ to 349 γ.	350 γ to 399 γ.	400 γ to 449 γ.	450 γ to 499 γ.	500 γ to 549 γ.	550 γ to 599 γ.	600 γ to 649 γ.	650 γ to 699 γ.	700 γ to 749 γ.	750 γ to 799 γ.	800 γ to 849 γ.	850 γ to 899 γ.	900 γ to 949 γ.	950 γ to 999 γ.
1932 Aug.	..	5	5	..	6	..	..	2	2	2	2	1	1	..	4	..	..	..	1	
Sept.	..	5	2	1	3	2	4	1	3	2	3	1	..	..	..	..	1	..	..	2
Oct.	..	8	2	..	1	5	3	2	..	1	2	2	2	1	1	..	..	1		
Nov.	..	4	3	4	2	5	4	4	2	1	..	..	..	..	..	..	..	..	1	
Dec.	..	2	5	7	3	1	5	2	2	..	1	..	2	..	..	1				
1933 Jan.	3	7	2	..	..	2	2	6	3	4	..	1	1							
Feb.	2	5	4	2	4	1	3	1	1	3	..	1	..	1						
Mar.	1	3	4	2	4	3	3	2	1	1	..	1	2	3	1					
Apr.	..	1	3	4	3	3	4	1	2	2	1	1	1	..	1	..	1	1		
May	..	2	6	2	5	4	3	1	3	..	2	..	1	1	1					
June	..	3	4	5	1	4	7	3	..	1	1	..	1							
July	..	1	8	5	3	3	4	2	3	..	..	1	..	..	1					
Aug.	..	7	4	2	2	2	1	1	2	2	2	3	..	2	..	..	..	..	..	1

with the range distribution discussed above for Fort Rae, it is of interest to note that the ranges of maximum frequency at Lerwick during the same period fell in the intervals 50–59 γ for H and D and 20–29 γ for Z: much the same was true for Eskdalemuir Observatory.

§ 68. *Diurnal distribution of times of incidence of maxima and minima.*—Table 59 summarises the frequency of occurrence of the times of incidence of the extreme values in H, D, and Z during the 24 hours of the Greenwich day. Where a maximum or a minimum value has occurred at a time indistinguishable from the exact hour, each of the adjacent hourly intervals have been assigned a half value.

If the regular diurnal variations of the elements were not overlaid by short period irregular disturbance, the times of incidence of the extreme values would

TABLE 57.—SEASONAL SUMMARIES OF FREQUENCY DISTRIBUTIONS OF ABSOLUTE DAILY RANGE AND PERCENTAGE DISTRIBUTIONS.

Range Interval. γ.	Number of Occurrences during Thirteen Months.			Number of Occurrences in Separate Seasons.									Percentage Distributions.												Range Interval. γ.
				H.			D.			Z.			H.				D.				Z.				
	H.	D.	Z.	*w.*	*e.*	*s.*	*w.*	*e.*	*s.*	*w.*	*e.*	*s.*	*y.*	*w.*	*e.*	*s.*	*y.*	*w.*	*e.*	*s.*	*y.*	*w.*	*e.*	*s.*	
0–49	2	6	4	2	..	..	5	1	..	3	1	..	0·5	1·7	..	..	1·5	4·2	0·8	..	1·2	2·5	0·8	..	0–49
50–99	13	53	28	7	4	2	18	17	18	10	9	9	3·3	5·8	3·3	1·3	13·4	15·0	14·0	11·7	7·2	8·3	7·6	5·8	50–99
100–149	23	52	21	7	9	7	14	11	27	8	4	9	5·8	5·8	7·4	4·5	13·2	11·7	9·1	17·5	5·4	6·7	3·4	5·8	100–149
150–199	24	34	28	7	7	10	13	7	14	8	10	10	6·1	5·8	5·8	6·5	8·6	10·8	5·8	9·1	7·2	6·7	8·5	6·5	150–199
200–249	22	37	18	5	6	11	9	11	17	5	2	11	5·6	4·2	5·0	7·1	9·4	7·5	9·1	11·0	4·6	4·2	1·7	7·1	200–249
250–299	34	35	29	9	7	18	9	13	13	8	6	15	8·6	7·5	5·8	11·7	8·9	7·5	10·7	8·4	7·4	6·7	5·1	9·7	250–299
300–349	24	43	40	6	9	9	14	14	15	15	12	13	6·1	5·0	7·4	5·8	10·9	11·7	11·6	9·7	10·2	12·5	10·2	8·4	300–349
350–399	23	28	30	9	5	9	13	6	9	8	9	13	5·8	7·5	4·1	5·8	7·1	10·8	5·0	5·8	7·7	6·7	7·6	8·4	350–399
400–449	31	24	22	11	9	11	8	6	10	6	7	9	7·9	9·2	7·4	7·1	6·1	6·7	5·0	6·5	5·6	5·0	5·9	5·8	400–449
450–499	27	19	24	9	5	13	8	6	5	6	7	11	6·8	7·5	4·1	8·4	4·8	6·7	5·0	3·2	6·1	5·0	5·9	7·1	450–499
500–549	21	14	26	7	8	6	1	6	7	13	5	8	5·3	5·8	6·6	3·9	3·5	0·8	5·0	4·5	6·6	10·8	4·2	5·2	500–549
550–599	24	12	16	12	6	6	2	5	5	7	2	7	6·1	10·0	5·0	3·9	3·0	1·7	4·1	3·2	4·1	5·8	1·7	4·6	550–599
600–649	20	11	15	7	8	5	3	5	3	5	5	5	5·1	5·8	6·6	3·3	2·8	2·5	4·1	1·9	3·8	4·2	4·2	3·2	600–649
650–699	15	8	15	2	5	8	1	4	3	3	6	6	3·8	1·7	4·1	5·2	2·0	0·8	3·3	1·9	3·8	2·5	5·1	3·9	650–699
700–749	14	9	14	2	7	5	..	3	6	4	5	5	3·5	1·7	5·8	3·3	2·3	..	2·5	3·9	3·6	3·3	4·2	3·2	700–749
750–799	12	1	14	2	3	7	1	..	..	1	7	6	3·0	1·7	2·5	4·5	0·3	0·8	..	..	3·6	0·8	5·9	3·9	750–799
800–849	14	2	13	2	6	6	..	2	..	3	6	4	3·5	1·7	5·0	3·9	0·5	..	1·7	..	3·3	2·5	5·1	2·6	800–849
850–899	10	2	8	4	3	3	..	2	..	1	2	5	2·5	3·3	2·5	1·9	0·5	..	1·7	..	2·2	0·8	1·7	3·2	850–899
900–949	5	2	5	2	..	3	1	..	1	2	3	..	1·3	1·7	..	1·9	0·5	0·8	..	0·6	1·3	1·7	2·5	..	900–949
950–999	7	3	7	..	3	4	..	2	1	1	4	2	1·8	..	2·5	2·6	0·8	..	1·7	0·6	1·8	0·8	3·4	1·3	950–999
1000–1049	6	..	2	1	3	2	..	..	..	1	1	..	1·5	0·8	2·5	1·3	..	..	..	..	0·5	0·8	0·8	..	1000–1049
1050–1099	4	..	3	1	1	2	..	..	..	1	..	2	1·0	0·8	0·8	1·3	..	..	..	..	0·8	0·8	..	1·3	1050–1099
1100–1149	3	..	4	2	1	..	..	..	..	1	2	1	0·8	1·7	0·8	..	..	..	..	..	1·2	0·8	1·7	0·7	1100–1149
1150–1199	4	..	3	1	2	1	..	..	..	..	2	1	1·0	0·8	1·7	0·6	..	..	..	..	0·8	..	1·7	0·7	1150–1199
1200–1249	3	..	..	1	1	1	..	..	..	..	..	..	0·8	0·8	0·8	0·6	..	..	..	..	..	..	..	..	1200–1249
1250–1299	3	..	2	1	2	..	..	..	..	..	..	2	0·8	0·8	1·7	..	..	..	..	..	0·5	..	..	1·3	1250–1299
$\geqslant$ 1300	7	..	1	1	1	5	..	..	..	..	1	..	1·8	0·8	0·8	3·3	..	..	..	..	0·3	..	0·8	..	$\geqslant$ 1300

TABLE 58.—DISTRIBUTION OF D RANGES (AS ANGLES) IN YEAR AND SEASONS.

Range Interval.		No. of Occurrences.				Percentages.			
In Degrees.	In Mins.	*y.*	*w.*	*e.*	*s.*	*y.*	*w.*	*e.*	*s.*
0 to 1	0–19	5	5	0	0	1·3	4·2	0	0
	20–39	40	14	12	14	10·1	11·7	9·9	9·1
	40–59	51	15	15	21	12·9	12·5	12·4	13·6
1 to 2	60–79	33	10	5	18	8·4	8·3	4·1	11·7
	80–99	32	11	8	13	8·1	9·2	6·6	8·4
	100–119	35	6	12	17	8·9	5·0	9·9	11·0
2 to 3	120–139	32	12	10	10	8·1	10·0	8·3	6·5
	140–159	41	14	13	14	10·4	11·7	10·7	9·1
	160–179	20	9	5	6	5·1	7·5	4·1	3·9
3 to 4	180–199	23	7	6	10	5·8	5·8	5·0	6·5
	200–219	16	7	5	4	4·0	5·8	4·1	2·6
	220–239	13	2	6	5	3·3	1·7	5·0	3·2
4 to 5	240–259	15	2	5	8	3·8	1·7	4·1	5·2
	260–279	6	0	5	1	1·5	0	4·1	0·6
	280–299	9	4	3	2	2·3	3·3	2·5	1·3
5 to 6	300–319	7	0	2	5	1·8	0	1·7	3·2
	320–339	8	1	3	4	2·0	1·2	2·5	2·6
	340–359	1	0	1	0	0·3	0	1·2	0
$\geqslant$6°	360	8	1	5	2	2·0	1·2	4·1	1·3

be highly concentrated in a very few hours and could be immediately deduced from the mean variations in fig. 6. Table 59 shows, however, that irregular disturbance plays a considerable part in determining the times of occurrence of the extreme values.

§ 69. *Diurnal incidence of extreme values in* Z.—In Z the greatest number of maxima occur at 9–10h G.M.T. (1–2h Z.M.T.), and the greatest number of minima occur only two hours earlier at 7–8h G.M.T. In winter only one hour separates the most frequent times of highest and lowest values. But the turning values of the regular daily variation in this component are separated by about seven hours, and neither of them occurs at the time indicated by the extremes of Table 59. The explanation is that about local midnight (8h G.M.T.) short period irregular disturbance is most prevalent and of greatest magnitude, so that sharp oscillations with a range exceeding that of the regular variation frequently furnish both of the extreme values for the day within a very short time of each other.

TABLE 59.—DIURNAL DISTRIBUTION OF TIMES OF INCIDENCE OF EXTREME (MAXIMUM AND MINIMUM) VALUES OF THREE PRIMARY ELEMENTS H, D, AND Z.

G.M.T. Hour Ending			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
H	Max.	*y*	69	49	36	32½	26	23	18	10	7	3	..	2	..	3	3	4	..	1	2	1	6	11	25	64½
		w	13	13	7	8	9	11	9	7	6	2	..	1	..	1	1	3	..	1	2	..	2	6	7	11
		e	28	10	10	9	10	5	4	3	1	1	..	..	..	1	2	..	..	..	..	..	4	4	9	21
		s	28	26	19	15½	7	7	5	..	..	..	..	1	..	1	..	..	..	..	..	1	..	1	9	32½
	Min.	*y*	..	..	1	3	3	13	38½	57	53	48	45	19½	16	31	20	24	5	6	5	1	3	1	2	..
		w	..	..	..	1	..	2	3½	12	22	11	20	7½	7	15	2	8	1	4	1	1	1	..	1	..
		e	..	..	..	2	2	8	9	20	11	15	13	6	6	7	6	10	2	..	2	..	1	1	..	..
		s	..	..	1	..	1	3	26	25	20	22	12	6	3	9	12	6	2	2	2	..	1	..	1	..
D	Max.	*y*	..	..	..	4	8	13	31	33	30	25	23	21	23	38	47	48	31	16	2	1	..	..	..	..
		w	..	..	..	1	1	4	8	13	16	6	9	6	12	15	8	9	6	5	..	1	..	..	..	..
		e	..	..	..	3	5	6	9	9	7	7	8	5	6	9	15	18	8	4	1	..	..	..	..	..
		s	..	..	..	..	2	3	14	11	7	12	6	10	5	14	24	21	17	7	1	..	..	..	..	..
	Min.	*y*	7	4	7	4	9	19	43	95	87	51½	11	3	..	3	1	..	..	1	2	6	15½	7	10	9
		w	1	..	..	2	1	6	6	26	29	20½	7	2	..	1	..	..	..	1	2	5	6½	1	2	1
		e	1	..	2	1	3	7	16	33	26	14	3	..	..	..	..	..	..	..	..	1	5	3	4	2
		s	5	4	5	1	5	6	21	36	32	7	1	1	..	2	1	..	..	..	..	..	4	3	4	6
Z	Max.	*y*	5	7	2	2	1	1	8	22½	55½	65	60	43	35	33	21	10	2	3	..	2	1	2	3	8
		w	3	3	1	1	1	..	1	5½	20½	19	20	12	11	10	3	2	..	1	..	2	..	1	1	2
		e	2	2	..	..	..	1	3	7	15	22	18	11	10	8	9	5	..	1	..	..	1	1	1	1
		s	..	2	1	1	..	..	4	10	20	24	22	20	14	15	9	3	2	1	..	..	..	..	1	5
	Min.	*y*	3	8	8	14	18	49	66	85½	58½	20½	3	1	2½	1	6	8	15	9	7	3	2	..	1	3
		w	..	1	..	2	4	13	14	29½	27	9½	1	1	2	1	3	3	3	3	..	1	1	..	1	..
		e	1	3	3	8	9	16	15	26	13	6	2	..	..	..	3	2	5	1	3	..	..	..	..	2
		s	2	4	5	4	5	20	37	30	18½	5	..	..	½	..	..	3	7	5	4	2	1	..	..	1

It has already been noted in the paragraphs dealing with the regular diurnal variation that the average vertical force variation at Fort Rae, with its morning maximum and evening minimum, is of the type peculiar to localities northward of the zone of maximum overhead current concentration. From other evidence (see *e.g.* § 54) it is known that this zone is not constant in position, but advances southward in summer and possibly also during periods of greatest disturbance. It is therefore of interest to use the evidence of Table 59 for examining whether and how frequently the current line moves to the north of Fort Rae. This would be shown by a reversal of type of the diurnal variation to evening maximum and morning minimum; in particular, the maximum would fall between 20–22h Z.M.T. (4–6h G.M.T.). There are only 2 occasions (out of 392) of maxima occurring in this period, and only 3½ occasions of the minimum occurring between 12h and 14h G.M.T. when the maximum of the daily variation occurs. All these occasions were on very quiet days interrupted by irregular and quite minor perturbations, except September 9 when an isolated peak between 5h and 6h produced an irregular maximum in an otherwise moderately disturbed day. Even if the evidence of the diurnal variations derived from a group of selected most disturbed days (fig. 7) were not available, this result confirms that throughout the year and for all grades of disturbance experienced during 1932–33 Fort Rae remains to the north of the zone of maximum current concentration.

§ 70. *Incidence of extreme values in* H *and* D.—Differing remarkably from the vertical component in the resultant effect of short period disturbance displacing the times of incidence of extremes from those of the regular variation, H has the greatest concentration of times of maxima (0–1h G.M.T.) at the maximum of the regular variation. Except in summer, however, most of the minima are affected by the prevalence and concentration of disturbance near local midnight in the same way as the maxima and minima of Z, being displaced from 13–14h to 7–8h, though in H there is a subsidiary concentration of times of lowest values at the time of real minimum of the regular variation.

Declination behaves like H in that the concentration of maxima occurs about the time of most easterly declination in the diurnal variation (15–16h G.M.T.), though with a secondary concentration at local midnight. The regular variation in D makes this element a minimum (*i.e.* most westerly) at local midnight on the average of all days, so, reinforced by the irregular disturbance then, the concentration of D minima at 7–8h G.M.T. is greater than for either of the extremes of the other elements in any one hour.

§ 71. *Daily range products* HR_H, ZR_Z.—To supply data for Fort Rae corresponding with those now being published for selected observatories in an attempt to obtain a numerical measure for the magnetic characterisation of days, the quantities $HR_H . 10^{-4}$ and $ZR_Z . 10^{-4}$ and their combination $(HR_H + ZR_Z) . 10^{-4}$ have been formed for all days of available R at Fort Rae. Rounded mean values, 7730 γ for H and 59,960 γ for Z, were used throughout the 13 months. The separate daily values of $HR_H . 10^{-4}$ and $ZR_Z . 10^{-4}$ are not published, but those of the added products $(HR_H + ZR_Z) . 10^{-4}$ in γ^2 units are entered in those tables in Vol. II, one for each month, which give the daily details of maxima and minima. Monthly and seasonal means of $(HR_H + ZR_Z) . 10^{-4}$ and its constituents are given in Table 60. In forming the year (*y*) and summer (*s*) means in this table the mean of the two values for August has been taken as representing that month. The value 441 for $HR_H . 10^{-4}$ for April is derived from 29 complete days; the mean for the same 26 days (April 5–30) as contributed to $ZR_Z . 10^{-4}$ is 452.

TABLE 60.—MONTHLY MEAN VALUES OF DAILY RANGE PRODUCTS : UNIT 1 γ^2.

	1932.					1933.											
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	*y.*	*w.*	*e.*	*s.*
$\overline{HR}_H . 10^{-4}$.	458	448	356	343	390	343	381	387	441	403	362	368	408	388	364	408	391
$\overline{ZR}_Z . 10^{-4}$.	2866	3265	2759	2372	2483	2305	2613	2948	3027	2653	2759	2371	2698	2695	2443	3000	2641
$(\overline{HR}_H + \overline{ZR}_Z) . 10^{-4}$	3324	3712	3115	2715	2872	2648	2994	3335	3478	3056	3121	2739	3105	3083	2807	3410	3033

The results of Table 60 will be used more fully later. Here it need only be said that the seasonal order of diminishing value of CR (which will be used to denote $(HR_H + ZR_Z) . 10^{-4}$) and its constituent products is *e*, *s*, and *w*. The difference between the *e* and *w* values of CR is only 18% of the *e* value.

To determine whether these seasonal differences are due to differences in the distribution of days of high CR value or to a greater or less prevalence of moderate

CR, a table was formed showing the number of days in each month having CR within specified limits. Table 61 summarises the results of this analysis by showing

TABLE 61.—DISTRIBUTION OF DAYS ACCORDING TO $(HR_H + ZR_Z) . 10^{-4}$ VALUE.

Interval Limits, γ^2.	*w.*	*e.*	*s.*	*y.*
0–499	7	3	4	14
500–999	13	10	10	33
1000–1499	10	11	21	42
1500–1999	10	5	15	30
2000–2499	16	19	18	53
2500–2999	13	10	20	43
3000–3499	12	10	11	33
3500–3999	15	5	15	35
4000–4499	6	8	5	19
4500–4999	4	7	10	21
5000–5499	4	9	9	22
5500–5999	3	8	7	18
6000–6499	3	4	1	8
6500–6999	1	4	2	7
7000–7499	2	1	..	3
7500–7999	1	2	3	6
8000–8499	..	1	2	3
8500–8999	..	..	1	1
9000–9499	..	1	..	1
Total Number Contributing Days	120	118	154	392

the months grouped together into seasons, the *s* of which includes both Augusts and so has five contributing months. By a further grouping of the number of occurrences of CR values not less than

(i) The average for the whole year, (rounded to) 3000 γ^2, and
(ii) 5000 γ^2,

the results in Table 62, were obtained. From these it is clear that not only are days of CR greater than the average more frequent in *e* than in *s* or *w*, but the table also shows that days of the greatest CR values are most frequent in *e* and more frequent in *s* than *w*.

TABLE 62.—FREQUENCY OF DAYS OF GREATEST VALUE OF CR.

	w.	*e.*	*s.*	*y.*
Number of days $\geqslant 3000\ \gamma^2$.	51	60	66	177
,, $\geqslant 5000\ \gamma^2$.	14	30	25	69
Percentage number of days $\geqslant 3000\ \gamma^2$.	43	51	42	45
,, ,, ,, $\geqslant 5000\ \gamma^2$.	12	25	16	18

Table 61 shows that at the other end of the scale there were only 47 days in the 13 months having CR less than 1000 γ^2. As percentages of the total number of days in each season these were distributed as follows: 16·7% to *w*, 11·0% to *e*, and 9·1% to *s*.

The 14 days of greatest and 14 days of least CR are listed in Table 63.

As an expression designed to measure some features of daily changes in the earth's magnetic field, CR is difficult to interpret, and as a measure of disturbance it has many defects. Since the ranges R_H and R_Z in the products comprising CR are seldom measured between precisely the same instants for the two components, CR bears only a superficial resemblance to the joint-energy constituent in the complete integral for the energy of the earth's magnetic field at any instant. Nevertheless, its possibilities as a numerical measure of one aspect of disturbance are at present being explored, and with this in mind CR has been used to examine, *inter alia*, the variation of disturbance with latitude. Reference has already been made to some of the more outstanding results of this inquiry in § 66. Further use will be made of the CR data in subsequent paragraphs (see *e.g.* §§ 76, 78).

TABLE 63.—DAYS OF GREATEST AND LEAST VALUE OF CR DURING 13 MONTHS.

Greatest.		Least.	
Date.	$(HR_H+ZR_Z).10^{-4}$.	Date.	$(HR_H+ZR_Z).10^{-4}$.
	γ^2		γ^2
1932 Aug. 28	7824	1932 Oct. 6	482
29	7522	12	381
Sept. 20	8069	14	305
25	7773	Nov. 24	151
Oct. 21	7491	1933 Jan. 4	454
Nov. 16	7205	10	457
Dec. 9	7207	12	286
1933 Feb. 23	7573	21	377
Mar. 21	9028	Feb. 6	453
Apr. 17	7818	11	227
May 1	8225	May 12	444
June 13	8195	Aug. 1	465
14	7557	12	448
Aug. 5	8690	31	416

§ 72. *Hourly ranges and hourly range products.*—The extreme range within each hour was measured on all (392) days of complete records in the three components H, D, and Z. For H and Z the ranges r_H and r_Z in mm. were converted directly into the products Hr_H and Zr_Z by a factor incorporating the scale value of the records and the mean values of the force components. This was done at an early stage of the reduction of the data before it was discovered that the mean value of H and therefore of Z required adjustment to take account of a revised calibration of the resistance introduced into the potentiometer of the Smith magnetometer (§ 8). The necessary adjustment was $+20\,\gamma$ for H and $+155\,\gamma$ for Z. For the 11 months, August 1932 to June 1933, during which the scale values of the H and Z records remained constant, the factor used in converting the hourly ranges in mm. to $Hr_H.10^{-4}$ in γ^2 units was $(7714\times13{\cdot}75).10^{-4}=10{\cdot}61$. This was rounded to 10·6 for multiplication by three-figure tables. The true factor would have been 10·63, which would likewise have been rounded to 10·6. For the Z components the factor as actually used was $(59{,}800\times11{\cdot}25).10^{-4}=67{\cdot}275$, which was rounded to 67·3. The factor should have been 67·45. Hence, while the increase in the mean value of H from 0·07714 to 0·07734 left the working factor unchanged, the corresponding alteration in Z introduced an error in $Zr_Z.10^{-4}$, as it was computed, of about 0·14%. This was considered insignificant, and no adjustments were made. For the months June–August 1933 appropriate changes were naturally made in the conversion factors of both components to allow for the changing instrumental scale value during those months.

For declination, the hourly ranges as measured in mm. on the records from the Greenwich magnetograph were converted into minutes of arc only. To form their equivalent in force units across the meridian the arc ranges require multiplication by a factor 2·25.

The aim in forming the products $Hr_H \cdot 10^{-4}$ and $Zr_Z \cdot 10^{-4}$ was to derive a combination product $(Hr_H + Zr_Z) \cdot 10^{-4}$ for each hour, on the analogy of the expression $(HR_H + ZR_Z) \cdot 10^{-4}$ for each day, with the object of investigating the diurnal distribution of irregular disturbance in so far as this could be measured by a function of the hourly ranges. There was no intention of using the values of r_D further than to confirm that the behaviour of irregular disturbance in declination differed in no noteworthy way from the behaviour of irregular disturbance in H and Z. At a recent meeting of the Commission of Terrestrial Magnetism and Atmospheric Electricity, Warsaw, 1935, however, it has been urged that individual hourly ranges should, as far as possible, be made available at certain selected stations of which Fort Rae is one. Tables 232 to 270 of Vol. II therefore give the values in each hour of the quantities $Hr_H \cdot 10^{-4}$, $Zr_Z \cdot 10^{-4}$, and r_D. The simple force ranges r_H and r_Z in γ can be derived from the range products $Hr_H \cdot 10^{-4}$ and $Zr_Z \cdot 10^{-4}$ by multiplying throughout by the factors 1·296 and 0·167 respectively. By analogy with the daily numerical character figure, $CR = (HR_H + ZR_Z) \cdot 10^{-4}$ derived from the over-all absolute range R for each day, a second daily numerical character figure Cr based on the range in each hour has been evaluated by adding $\overline{Hr}_H \cdot 10^{-4}$ and $\overline{Zr}_Z \cdot 10^{-4}$ where $\overline{Hr}_H \cdot 10^{-4} = \frac{1}{24}\sum_{n=1}^{n=24} Hr_{H(n)} \cdot 10^{-4}$ and similarly for $\overline{Zr}_Z \cdot 10^{-4}$. The daily values of Cr are given in Tables 163, 167, etc. of Vol. II; the monthly and seasonal means of Cr and its constituents $\overline{Hr}_H \cdot 10^{-4}$ and $\overline{Zr}_Z \cdot 10^{-4}$ are summarised in Table 64 together with the corresponding mean hourly ranges in each of the three components. In this table the April value of 86 γ^2 for Hr_H is derived from 27 days complete in r_H; if only the 26 days which form the corresponding mean of Zr_Z are used, the value would be 84 γ^2. For the same month (which is the only one of incomplete hourly ranges in any component) the mean value of r_D is derived from 29 days.

TABLE 64.—MONTHLY MEAN VALUES OF $Hr_H \cdot 10^{-4}$, $Zr_Z \cdot 10^{-4}$, Cr, AND THE SIMPLE HOURLY RANGES r_H, r_Z, AND r_D.

Month and Season.	$Hr_H \cdot 10^{-4}$.	$Zr_Z \cdot 10^{-4}$.	Cr.	r_H.	r_Z.	r_D.
	γ^2	γ^2	γ^2	γ	γ	′
1932 Aug.	82	523	605	106	87	30·5
Sept.	86	564	649	111	94	31·9
Oct.	66	460	527	86	77	26·3
Nov.	63	392	454	82	65	22·6
Dec.	68	423	491	88	71	23·6
1933 Jan.	67	412	479	87	69	23·0
Feb.	71	455	526	92	76	24·5
Mar.	75	494	569	97	83	27·2
Apr.	86	537	621	111	90	30·2
May	71	452	523	92	75	25·6
June	64	433	498	83	72	21·9
July	61	371	433	79	62	20·1
Aug.	70	446	516	91	75	25·1
y	71	456	528	92	76	25·6
w	67	420	488	87	70	23·4
e	78	514	591	101	86	28·9
s	68	435	504	88	73	24·6

Table 64 shows that for the whole year the mean hourly range in H is 92 γ, in Z 76 γ, and in D 25·6′ or 58 γ in equivalent force units. In all three elements the range is highest in the equinoctial months and only slightly higher in summer than in winter. Except in H, for which element the mean hourly ranges for September and

April are equal, the months of greatest and least r are September and July, and for these extreme months the difference amounts to 41% in H, 52% in Z, and 59% in D.

TABLE 65.—FREQUENCY DISTRIBUTION OF r_H, r_Z, AND r_D IN FOUR REPRESENTATIVE MONTHS.

	r_H.												
	0 γ to 99 γ.	100 γ to 199 γ.	200 γ to 299 γ.	300 γ to 399 γ.	400 γ to 499 γ.	500 γ to 599 γ.	600 γ to 699 γ.	700 γ to 799 γ.	800 γ to 899 γ.	900 γ to 999 γ.	1000 γ to 1099 γ.	1100 γ to 1199 γ.	1200 γ to 1299 γ.
1932 Sept. . .	486	111	56	27	21	9	4	4		1	1		
Dec. . .	518	151	45	18	6	2	1	2	..	..	..	..	1
1933 Mar. . .	510	124	66	20	12	6	1	4	..	1			
June . .	523	127	48	13	4	3	..	2					
Mean . . .	509_{25}	128_{25}	53_{75}	19_5	10_{75}	5_0	1_5	3_0	..	0_5	0_{25}	..	0_{25}

	r_Z.										
	0 γ to 99 γ.	100 γ to 199 γ.	200 γ to 299 γ.	300 γ to 399 γ.	400 γ to 499 γ.	500 γ to 599 γ.	600 γ to 699 γ.	700 γ to 799 γ.	800 γ to 899 γ.	900 γ to 999 γ.	1000 γ to 1099 γ.
1932 Sept. . .	514	97	51	25	16	6	5	5	1		
Dec. . .	586	95	36	15	4	6	2				
1933 Mar. . .	543	111	49	19	13	3	4	2			
June . .	543	111	43	14	5	2	..	..	1	..	1
Mean . . .	546_5	103_5	44_{75}	18_{25}	9_5	4_{25}	2_{75}	1_{75}	0_5	..	0_{25}

	r_D.							
	0′ to 49′.	50′ to 99′.	100′ to 149′.	150′ to 199′.	200′ to 249′.	250′ to 299′.	300′ to 349′.	350′ to 399′.
1932 Sept. . .	581	78	43	12	1	4	1	
Dec. . .	653	67	17	2	3	1	1	
1933 Mar. . .	630	77	26	5	4	2		
June . .	642	71	5	1	1			
Mean . . .	626_5	73_{25}	22_{75}	5_0	2_{25}	1_{75}	0_5	

§ 73. *Frequency distribution of hourly ranges in representative months.*—To afford some indication of how the ranges are distributed in size—that is, how the monthly means of Table 64 are made up—frequency distributions for equal intervals of r have been formed for four months representative of autumn, winter, spring, and summer. Summaries of these distributions are given in Table 65. For r_H and r_Z the intervals used were 100 γ, and for r_D 50 minutes of arc. Smaller intervals would have given more detailed insight into the distribution for any month, but since the results of Table 65 were intended only for comparison with the distributions of large r values in hours selected as representing various grades of auroral activity (§§ 115, 116) it was thought unnecessary to extend the analysis further.

The mean ranges from all hours of the four months used in Table 65 are 95 γ for r_H, 80 γ for r_Z, and 26·1′ for r_D. It is therefore not surprising that 94% and 95% respectively of all values of r_H and r_Z in the four months should be less than 300 γ, and that 95% of r_D values should be less than 100′; a more instructive feature of the table is the relatively high frequency of occurrence of hourly ranges in excess of those and higher values. Judged by the four months of Table 65, hourly ranges exceeding 500 γ may occur in both H and Z once every three days approximately, and an hourly range greater than $2\frac{1}{2}°$ in D can be expected in about the same time.

It is pertinent to the present considerations to anticipate here some later results to be given in connection with the average effects of disturbance on the hourly ranges. From all hours of 38 selected quietest days the mean value of r_H was 22 γ,

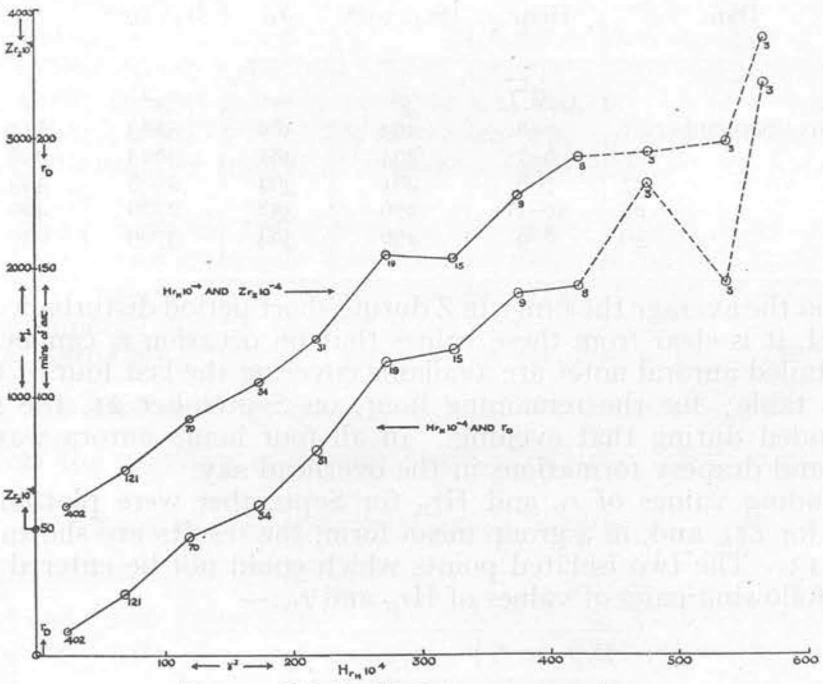


FIG. 13.—Relationship between r_H, r_Z, and r_D.

of r_Z 14 γ, and of r_D 5·7′; the corresponding values from the 40 *d′* days were 217 γ, 193 γ, and 64·5′. The largest individual value of r_H on any one of the *q′* days was 166 γ and on any one of the *d′* days 1258 γ; for Z and D the corresponding maxima were 113 γ and 1079 γ, and 37·2′ and 422·0′ respectively.

§ 74. *Relationships among* r_H, r_Z, *and* r_D.—Taking September 1932 as a representative month, all the 720 values of $Zr_Z \cdot 10^{-4}$ in that month have been plotted against the corresponding values of $Hr_H \cdot 10^{-4}$. As might have been anticipated, the dot distribution diagram so formed shows a considerable scatter even in the moderate range values of Hr_H. (In the subsequent discussion the factor 10^{-4} in the range products will not be written.) For example, the values of Zr_Z corresponding with the two comparatively close Hr_H values of 262 γ^2 and 294 γ^2 are 1050 γ^2 and 3823 γ^2, or, in terms of simple ranges, r_Z is 175 γ when r_H is 340 γ, and r_Z is 638 γ when r_H is 381 γ. The detailed dot diagram is not reproduced, but in the upper curve of fig. 13 mean values of Zr_Z are plotted against the corresponding means of Hr_H when these latter have been grouped in 50 γ^2 intervals. The figure against each circle in this diagram refers to the number of corresponding pairs of values used in determining the group mean, and the last three group circles have been connected by broken lines because the contributing numbers are so unreliably small. Two isolated and high values of Hr_H could not be represented in the figure. With the corresponding values of Zr_Z they are:

$Hr_H \cdot 10^{-4}$.	r_H.	$Zr_Z \cdot 10^{-4}$.	r_Z.
γ^2	γ	γ^2	γ
714	924	4590	766
814	1053	4321	722

Apart from the highest three groups and, to a less extent, the group derived from the Hr_H interval of 250 to 299 γ^2, the Hr_H and Zr_Z curve of fig. 13 shows that the average relationship between the two force ranges is approximately linear over a wide range of values of both and could be represented by $r_H = 0{\cdot}87\ r_Z$. Of the 19 pairs contributing to the interval mean $Hr_H = 250$ to $299\ \gamma^2$, 5 have unusually high Zr_Z values. The times of occurrence and magnitudes involved were as follows:—

Date.	Hour.	$Hr_H \cdot 10^{-4}$.	r_H.	$Zr_Z \cdot 10^{-4}$.	r_Z.
	G.M.T.	γ^2	γ	γ^2	γ
1932 September 21	7–8	293	380	3183	532
27	6–7	294	381	3823	638
27	7–8	281	364	2988	499
27	10–11	276	358	2786	466
30	8–9	296	384	3769	630

Though on the average the range in Z during short period disturbance is somewhat less than in H, it is clear from these values that on occasion r_Z can be 70% greater than r_H. Detailed auroral notes are available covering the last four of the five hours in the above table; for the remaining hour, on September 21, the sky was continuously clouded during that evening. In all four hours aurora was very active, with curtain and drapery formations in the overhead sky.

Corresponding values of r_D and Hr_H for September were plotted in a similar way to those for Zr_Z, and, in a group mean form, the results are shown in the lower graph of fig. 13. The two isolated points which could not be entered in this figure relate to the following pairs of values of Hr_H and r_D:—

$Hr_H \cdot 10^{-4}$.	r_H.	r_D.
γ^2	γ	′
714	924	158·2
814	1053	197·1

As with the ranges in the two force components, the relationship between Hr_H and r_D is approximately linear up to the stage when the group means are unreliable, being derived from too small a number of hours. Taking September as representative of a wide range of values, the relationship in terms of hourly ranges can be expressed in the form $r_H = 0{\cdot}29 r_D\,(') = 0{\cdot}65 r_D\,(\gamma)$. It is worth noting that the anomalously high group mean for r_D in the interval $Hr_H = 250$ to $299\ \gamma^2$ has its greatest contribution from three of the five hours in which r_Z was also unusually high relatively to r_H. The disturbing vector in those hours was more than usually orthogonal to the meridian.

§ 75. *Relative magnitude of perturbations in* H *and* Z.—The values of the ratio r_H/r_Z derived from the seasonal mean values of these quantities given in Table 64 are:

y.	*w.*	*e.*	*s.*
1·21	1·24	1·18	1·21

For the corresponding ratio R_H/R_Z the values are:

y.	*w.*	*e.*	*s.*
1·12	1·16	1·05	1·15

Inferences from the values of these ratios can be only very general and uncertain. Even if the time interval within which the range is measured were limited to less than one hour, and if the values of the ratios in this shortened period were derived as the mean of individual ratios instead of the ratios of mean values, it would be seldom that the range in H and Z referred to exactly synchronous perturbations. Nevertheless, the approximate equality of the ranges in H and Z disclosed by the ratios is of interest. For the effect of primary atmospheric currents in inducing currents in the earth during disturbance should be to reduce the range of perturbations in the vertical vector component of the field relative to that in the horizontal plane. The extent of the reduction should depend on the completeness with which the induced earth current mirrors the primary current. In the neighbourhood of Fort Rae the distribution of the lines of current flow in the atmosphere or the resistivity of the earth must be such that considerations based on simple primary induced currents have little validity.

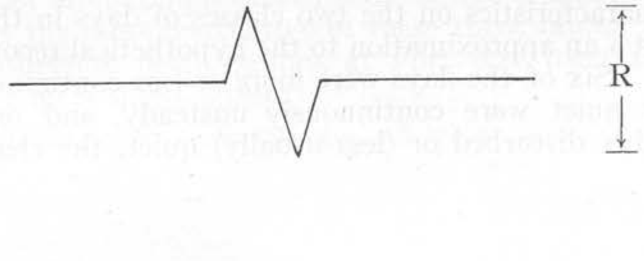
Among other features, the ratios quoted above would seem to indicate that within both hourly and 24-hourly intervals the range of perturbations in the vertical component more nearly approximates to the range in the horizontal component during the equinoctial months than at other times of the year.

§ 76. *The ratio* CR/C*r* : *its significance in the selection of days.*—Values of the ratio $\rho = \frac{CR}{Cr}$ have been evaluated for the 392 days for which both quantities are available. Table 66 gives the monthly frequency distribution of ρ. This ratio is an index of

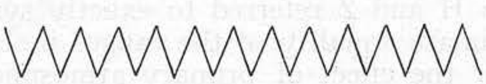
TABLE 66.—FREQUENCY DISTRIBUTION OF RATIOS $\rho = \frac{CR}{Cr}$.

	1·00–1·99.	2·00–2·99.	3·00–3·99.	4·00–4·99.	5·00–5·99.	6·00–6·99.	7·00–7·99.	8·00–8·99.	9·00–9·99.	10·00–10·99.	Total.
1932 Aug.	..	..	1	6	7	11	4	1	1	..	31
Sept.	..	..	2	3	5	11	8	1	..	..	30
Oct.	..	..	2	4	10	10	4	1	..	..	31
Nov.	..	..	1	7	6	7	6	3	..	..	30
Dec.	..	..	..	7	8	7	4	3	1	1	31
1933 Jan.	..	..	2	7	10	6	4	1	1	..	31
Feb.	..	..	1	3	12	4	4	2	..	2	28
Mar.	..	..	..	6	9	7	5	1	3	..	31
Apr.	..	..	..	6	11	4	3	..	2	..	26
May	..	..	..	5	7	11	4	4	..	..	31
June	..	..	..	2	7	14	6	1	..	..	30
July	..	..	..	2	10	9	8	2	..	..	31
Aug.	..	..	..	2	14	9	2	3	1	..	31
Totals	..	..	9	60	116	110	62	23	9	3	392

some of the characteristics of disturbance. If there were no variations in field strength in either H or Z throughout the day except for a movement of range R confined to one hour, so that the record in either component could be represented like this:



ρ would be 24, provided only that $\frac{R_H}{R_Z}=\frac{r_H}{r_Z}$, which is approximately realised at Fort Rae (§ 75). Again, if each of the 24 hours had the same range, and the mean field in each hour remained constant so that the record could be represented like this:



ρ would be 1. In practice neither of these extreme values is ever attained. At Fort Rae the mean value of ρ was 6·21, the lowest 3·20, and the highest 10·99. There were nine days having ρ between 3·00 and 3·99, and twelve days between 9·00 and 10·99. For 94% of the 392 days ρ lay between 4·00 and 8·99, and for 89% between 4·00 and 7·99.

Table 67.—Characteristics of Records on Days of Least and Greatest ρ Values.

Date.	ρ Value.	Characteristics of Record (G.M.T. hours when given).
		Least ρ.
1932 Aug. 1	3·57	Fairly continuous small *d*; no isolated large perturbations.
Sept. 23	3·88	Very *d* throughout; no outstanding movement.
25	3·68	As in September 23.
Oct. 8	3·56	Moderately *q*; continuous unsteadiness from hour to hour but with no big movements.
12	3·31	As in October 8.
Nov. 24	3·60	*q* throughout.
1933 Jan. 26	3·81	Continuously *d* throughout but with no isolated large movements.
27	3·20	As in January 26.
Feb. 24	3·53	Continuously *d* with frequent large movements.
		Greatest ρ.
1932 Aug. 17	9·54	Very *q* day apart from one isolated movement 9–10h.
Dec. 23	9·04	*q* except for large bay movement 8–14h.
24	10·99	Very *q* and similar to December 23 only with major movement in bay more pronounced.
1933 Jan. 17	9·17	Very *q* except for large oscillating bay 8–13h; very similar to December 23–24.
Feb. 7	10·25	Fairly *q* except for bay 9–12h. Like December 23, 24 and January 17.
17	10·07	Very *q* except for little bay movements 9–13h.
Mar. 11	9·90	*q* for most part but with two well-defined bays.
16	9·58	Very *q* except for small bays 8–10 h.
26	9·75	Fairly *q* except for irregular bay movements 7–11h.
Apr. 11	9·06	Fairly *q* except for irregular bay movements 7–10h.
13	9·68	Like April 11.
Aug. 27	9·81	Very *q* except for irregular bay movements 9–12h with the bays 9–10h outstanding.

In view of the special characteristics of disturbance on days with least and greatest ρ values, and of the interest which would attach to a comparison of the simultaneous records from other localities, a list of the nine (Greenwich) days of least and twelve days of greatest ρ, with brief notes on the records, is given in Table 67. Summarising the characteristics on the two classes of days in this table, we find in all nine days of least ρ an approximation to the hypothetical record considered above when ρ would be 1. Six of the days were more or less continuously disturbed, two though moderately quiet were continuously unsteady, and one was very quiet throughout. Whether disturbed or (less usually) quiet, the characteristics of each record were similar from hour to hour throughout the day with no large pre-eminent movement.

On the other hand, the twelve days of greatest ρ were without exception quiet during the majority of the 24 hours, but invariably the quietness was interrupted for a few hours (one to three or four) by a movement of the 'bay' or other more irregular oscillatory type of short period perturbation.

It is of interest to note that the list of twelve days of ρ greater than 9·00 contains three pairs of days separated by 25–26 days, viz. December 23 and January 17, February 17 and March 16, and this last day with April 11. Though this is probably only a manifestation of the recurrence tendency after a solar synodic rotation of magnetic quiet in general, and not of particular types of movements, the similarity in form and in time of occurrence of the perturbations on December 23–24 and January 17 had been already noted before the days were numerically selected by their ρ values.

The average values of ρ in each month are as given in Table 68. The constancy

TABLE 68.—MONTHLY MEANS OF $\rho = CR/Cr$: FORT RAE.

1932.					1933.								Mean.
Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	
6·04	6·33	5·86	6·14	6·35	5·85	6·40	6·38	5·91	6·35	6·47	6·47	6·29	6·22

of the value from month to month is striking and, with the figures of Table 66 showing the distribution of ρ, leads to the conclusion that days of either of the two essentially different classes described above are fairly equally distributed throughout the year.

TABLE 69.—ANNUAL VALUES OF $F/\overline{A}$: ESKDALEMUIR.

Year 1900 +	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	Mean.
$F/\overline{A}$	·74	·76	·73	·77	·70	·73	·75	·69	·77	·73	·79	·78	·745

Dr A. Crichton Mitchell has computed values of a similar ratio for Eskdalemuir. Denoting $(XR_X + YR_Y + ZR_Z) \cdot 10^{-4}$ by F where R is the absolute daily range, and $\frac{1}{2}\{A_1 + A_2 + \ldots + A_{23} + \frac{1}{2}(A_0 + A_{24})\}$ by $\overline{A}$, where $A_n = (Xr_X + Yr_Y + Zr_Z) \cdot 10^{-3}$ and r is the hourly range, Mitchell * gives the mean annual values of $F/\overline{A}$ derived from the twelve years 1914–25. They are reproduced in Table 69. The ratios in this table require to be increased by a factor of ten for immediate comparison with ρ for Fort Rae, since A_n is ten times greater than Cr.

All the ratios of Table 69 are higher than the monthly mean values of ρ. This suggests that at Eskdalemuir disturbance is on the average more concentrated into a few hours of the day than at Fort Rae.

§ 77. *Seasonal Distribution of* Cr *and its constituents.*—Tables 70, 71, and 72 show the frequency distributions for all complete days of $\overline{Hr_H} \cdot 10^{-4}$ (393), $\overline{Zr_Z} \cdot 10^{-4}$ (392), and Cr. For the first two quantities the equivalent intervals in γ of the daily mean hourly ranges $\bar{r}_H$ and $\bar{r}_Z$ are given in the second line of the column headings. From the viewpoint of inter-comparison of short period magnetic activity in various localities Table 72 is the most instructive of these three tables, but for considering the scale of short duration perturbations at Fort Rae itself the distributions in terms of $\bar{r}_H$ and $\bar{r}_Z$ are more illuminating.

* A. C. Mitchell, Edinburgh, *Trans. Roy. Soc.*, vol. lvii, pt. iii, No. 23, p. 624 (1933).

TABLE 70.—SEASONAL FREQUENCY DISTRIBUTION OF $\overline{Hr}_H . 10^{-4}$.

$\overline{Hr}_H . 10^{-4}$ (γ^2).	0–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100–109	110–119	120–129	130–139	140–149	150–159	160–169	170–179	180–189	190–199	⩾200
Approximate equivalent $\bar{r}_H$ (γ).	0–13	13–26	26–39	39–52	52–65	65–78	78–91	91–104	104–117	117–130	130–142	142–155	155–168	168–181	181–194	194–207	207–220	220–233	233–246	246–259	⩾260
(13 months) y .	2	28	46	41	44	30	33	26	25	22	21	15	15	7	7	8	7	7	1	1	7
w .	2	12	15	10	13	7	11	7	9	9	6	4	5	..	3	2	3	1	..	..	1
e .	..	8	13	10	11	8	12	9	7	5	7	3	7	5	1	3	3	4	..	..	3
(5 months) s .	..	8	18	21	20	15	10	10	9	8	8	8	3	2	3	3	1	2	1	1	3

TABLE 71.—SEASONAL FREQUENCY DISTRIBUTION OF $\overline{Zr}_Z . 10^{-4}$.

$\overline{Zr}_Z . 10^{-4}$ (γ^2).	0–99	100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	1000–1099	1100–1199	1200–1299	1300–1399	1400–1499	1500–1599	1600–1699	1700–1799	1800–1899
Approximate equivalent $\bar{r}_Z$ (γ).	0–17	17–33	33–50	50–67	67–84	84–100	100–117	117–134	134–151	151–167	167–184	184–201	201–217	217–234	234–251	251–267	267–284	284–301	301–318
(13 months) y .	31	61	66	46	52	28	25	26	20	10	7	4	5	6	2	1	1	..	1
w .	12	20	21	15	14	8	11	6	3	3	2	2	..	3	..	..	..	..	..
e .	9	17	15	11	16	10	9	5	9	6	3	1	3	2	1	..	..	..	1
(5 months) s .	10	24	30	20	22	10	5	15	8	1	2	1	2	1	1	1	1	..	..

TABLE 72.—SEASONAL FREQUENCY DISTRIBUTION OF Cr.

$\overline{Hr_H + Zr_Z} . 10^{-4}$ (γ^2).	0–99	100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	1000–1099	1100–1199	1200–1299	1300–1399	1400–1499	1500–1599	1600–1699	1700–1799	1800–1899	>1900
(13 months) y .	18	54	58	50	34	47	24	23	21	19	9	12	5	4	6	2	3	1	1	1
w .	9	15	21	16	10	11	7	11	6	4	1	3	3	..	1	2	..	..	..	..
e .	4	18	13	9	13	15	9	6	4	7	4	7	1	2	3	..	2	..	..	1
(5 months) s .	5	21	24	25	11	21	8	6	11	8	4	2	1	2	2	..	1	1	1	..

On 29 days $\bar{r}_H$ was greater than $200\,\gamma$ ($\overline{Hr_H}\,.\,10^{-4} > 154\,\gamma^2$), but to obtain an approximately equal number (27) of days of greatest $\bar{r}_Z$ the limit must be lowered to include values of $\bar{r}_Z$ as low as $167\,\gamma$ ($\overline{Zr_Z}\,.\,10^{-4} \geqslant 1000\,\gamma^2$). These two sets of days are listed in Table 73. For the 29 days of greatest $\overline{Hr_H}\,.\,10^{-4}$ the mean value of this quantity was $181\,\gamma^2$, equivalent to an $\bar{r}_H$ of $235\,\gamma$; for the 27 days of greatest $\overline{Zr_Z}\,.\,10^{-4}$ the mean was $1259\,\gamma^2$, equivalent to an $\bar{r}_Z$ of $210\,\gamma$.

TABLE 73.—DAYS OF GREATEST $\overline{Hr_H}.10^{-4}$, $\overline{Zr_Z}.10^{-4}$, AND Cr.

$\overline{Hr_H}.10^{-4} > 154\,\gamma^2$ (equivalent $\bar{r}_H > 200\,\gamma$).		$\overline{Zr_Z}.10^{-4} \geqslant 1000\,\gamma^2$ (equivalent $\bar{r}_Z > 167\,\gamma$).		$Cr > 1200\,\gamma^2$.	
Date.	Value (γ^2).	Date.	Value (γ^2).	Date.	Value (γ^2).
1932 Aug. 3	200	1932 Aug. 3	1280	1932 Aug. 3	1480
27	165	28	1605	28	1879
28	274	29	1527	29	1741
29	214	30	1305	30	1484
30	179	Sept. 23	1305	Sept. 23	1473
Sept. 20	158	24	1233	24	1404
23	168	25	1875	25	2112
24	171	Oct. 15	1254	Oct. 15	1417
25	237	21	1202	21	1376
Oct. 15	163	Nov. 16	1302	Nov. 16	1471
21	174	Dec. 9	1056	Dec. 9	1205
Nov. 16	169	15	1123	15	1285
Dec. 14	155				
15	162				
1933 Jan. 27	161	1933 Feb. 22	1310	1933 Feb. 22	1520
Feb. 22	210	23	1116	23	1274
23	158	24	1342	24	1516
24	174	25	1029	Mar. 21	1664
Mar. 20	162	Mar. 21	1452	24	1345
21	212	22	1000	25	1212
24	159	24	1186	Apr. 17	1606
Apr. 17	213	25	1073	May 1	1660
20	175	Apr. 17	1393	18	1226
22	170	21	1025	June 13	1385
May 1	198	May 1	1465	Aug. 5	1376
31	158	18	1082		
June 1	156	June 13	1229		
July 24	178	Aug. 5	1195		
Aug. 5	181	21	1022		

Nineteen of the 27 days of greatest $\overline{Zr_Z}\,.\,10^{-4}$ coincide with 19 of the 29 days of greatest $\overline{Hr_H}\,.\,10^{-4}$, but 1932 August 28 was the day of maximum value of $\overline{Hr_H}\,.\,10^{-4}$ ($=274\,\gamma^2$, equivalent to an $\bar{r}_H$ of $350\,\gamma$), whereas the maximum $\overline{Zr_Z}\,.\,10^{-4}$ ($=1875\,\gamma^2$, equivalent to an $\bar{r}_Z$ of $315\,\gamma$) occurred on 1932 September 25.

Table 72, which gives the distribution of Cr, shows that though the most frequent value of Cr lies between $200\,\gamma^2$ and $299\,\gamma^2$, days with Cr between $600\,\gamma^2$ and $1000\,\gamma^2$ are almost equally distributed in the four intervals within that range, so that the distribution is not Gaussian. On 23 days Cr exceeded $1200\,\gamma^2$, all of which are included in the list (Table 73) of days of greatest $\overline{Zr_Z}\,.\,10^{-4}$. The 4 remaining days, 1933 February 25, March 22, April 21, and August 21, of that table would have appeared among the days of greatest Cr if the limiting value for this quantity had been lowered from $1200\,\gamma^2$ to $1146\,\gamma^2$. Twelve of the 14 days of greatest CR (Table 63) are included among the 23 days of greatest Cr. The 2 days not included are 1932 September 20 and 1933 June 13. Conversely, 17 of the 23 days of greatest C*r* are in the extended list (unpublished) of days of greatest CR.

The average value of C*r* on the 23 days of greatest value of that quantity is 1483 γ^2.

At the other end of the scale, the 18 days with C*r* less than 100 γ^2 are listed in Table 74. Twelve of the 14 days of least value of CR (Table 63) are included in this table. The average value of CR on the 18 days of Table 74 is 73 γ^2.

TABLE 74.—DAYS OF LEAST C*r*.

$(\overline{Hr_H + Zr_Z}) \cdot 10^{-4} < 100$.			
Date.	Value (γ^2).	Date.	Value (γ^2).
1932 Sept. 16	68	1933 Feb. 11	38
Oct. 7	89	13	92
14	72	17	58
Nov. 24	42	Mar. 7	98
1933 Jan. 4	76	May 12	67
10	86	Aug. 1	83
12	58	4	93
21	74	12	85
Feb. 6	76	31	61

§ 78. *Rank order of days in each month on basis of* CR *and* C*r* : *Comparison with international selection of* d *and* q *days.*—All days in each month have been arranged in rank order of decreasing values of CR and C*r* independently. The complete tabulation is not reproduced, but Table 75 gives the five days at the top and the five days at the bottom of each monthly list for both CR and C*r*. The purpose of this tabulation is to find what proportion of the (Greenwich) days which were most disturbed and most quiet at Fort Rae, as judged by the CR and C*r* criteria, coincided with the disturbed and quiet days selected by the international character scheme. It is assumed on fairly substantial ground that the four days 1933 April 1–4 for which CR and C*r* are not available were in neither of the extreme classes.

Of the 65 disturbed days selected by the De Bilt authorities for the 13 months August 1932 to August 1933, 37 are included in the lists of 65 days of greatest CR, and 40 in the list of greatest C*r*. Correspondingly, of the 65 international quiet days, 38 are included in the lists of least CR and 40 in the lists of least C*r*. Again, of the 65 days with greatest values of CR and 65 of greatest C*r*, 48 days are common, but the internationally selected list of 65 disturbed days contains only 33 of these days judged to be most disturbed by the double local criterion. Correspondingly, the two lists of 65 days of least CR and least C*r* have 56 days in common, but the international selection uses only 34, or only 60%, of those days selected as the quietest days at Fort Rae. The effect of omission of such a large proportion of the days truly representative of the two contrasting magnetic conditions naturally is that the inequalities formed for the days selected by the international arrangement do full justice neither to the truly disturbed nor to the truly quiet conditions at Fort Rae.

§ 79. *Effect of use of Greenwich day on selection of quiet and disturbed days.*—There is another aspect of this matter. Since both the regular and irregular disturbance diurnal variations are everywhere controlled by local time, and since in at least high latitudes the changes in the magnetic field brought about by that type of world-wide disturbance which is ushered in by sudden commencements are also very largely overlaid if not entirely controlled by these local time phenomena, coincidence in periods of disturbance defined by Greenwich time are *a priori* not to be expected at stations separated from the Greenwich meridian by substantial fractions of a whole day. Indeed, at a station like Fort Rae, $7\frac{3}{4}$ hours west of Greenwich, it might be expected that there would be many occasions when the days which would be selected as disturbed by local criteria would be found to be one day later than the days selected at De Bilt on the evidence of a preponderance of stations situated within a few hours of the Greenwich meridian. The lists of Table 75 show evidence of this: for example, 1932 December 8 is an isolated De Bilt disturbed day; 1932 December 9 is the corresponding isolated day either by the CR or Cr criterion. In the same month the remaining four internationally selected days are 14th, 15th, 16th, 17th, whereas both the CR and Cr lists give 14th, 15th, 17th, 18th. The 14th and 15th coincide, but instead of the 16th and 17th, the selected disturbed days from Fort Rae criteria would be each one day later. January 22 as an international day compared with January 23 as a CR day is another example. There are similar examples among the quiet days.

TABLE 75.—DATES OF GREENWICH DAYS ARRANGED IN RANK ORDER OF FIVE GREATEST AND FIVE LEAST VALUES OF CR AND Cr IN EACH MONTH.

	1932.					1933.							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
	(a) According to value of $(\mathrm{HR_H} + \mathrm{ZR_Z}) . 10^{-4}$.												
Greatest	28	20	21	16	9	28	23	21	17	1	13	24	5
	29	25	15	1	15	23	22	23	23	18	14	9	6
	3	24	16	2	18	6	26	20	18	4	9	18	25
	27	26	27	14	14	24	21	24	19	3	28	10	17
	30	23	25	12	17	15	25	25	22	6	1	17	21
Least .	16	17	8	8	21	5	10	16	29	8	12	15	11
	18	10	7	7	3	10	13	6	28	25	10	8	4
	19	11	6	10	5	4	17	8	13	27	5	3	1
	11	12	12	27	2	21	6	7	27	26	22	1	12
	24	16	14	24	7	12	11	9	12	12	23	13	31
	(b) According to value of $(\overline{\mathrm{H}}r_{\mathrm{H}} + \overline{\mathrm{Z}}r_{\mathrm{Z}}) . 10^{-4}$.												
Greatest	28	25	15	16	15	27	22	21	17	1	13	24	5
	29	23	21	14	9	28	24	24	21	18	14	9	21
	30	24	25	1	14	26	23	25	22	31	28	18	25
	3	27	20	17	17	29	25	22	20	6	29	23	19
	27	20	27	29	18	1	21	23	19	3	1	11	17
Least .	18	10	8	9	2	5	1	6	5	9	16	7	10
	17	11	12	7	3	10	13	8	11	27	22	1	4
	19	17	6	10	21	4	6	16	27	25	10	3	12
	11	12	7	27	5	21	17	9	12	26	5	15	1
	24	16	14	24	7	12	11	7	13	12	23	13	31

To see how this may come about, it is necessary only to consider a day in which disturbance is proceeding on a small scale throughout the first 16 hours and assumes greater proportions in the last 8 Greenwich hours of the day (fig. 14). This is not an unusual occurrence at European observatories. The effect of assigning a character figure at a station within a few hours (three to four) longitude of Greenwich would be for the increased disturbance in the last eight hours to make that day a 2 on the international scale. But at Fort Rae, with the corresponding disturbance delayed eight hours later by the local time control, these most disturbed hours, though in the local day of the same date, would fall into the next Greenwich day. Thus the selected Greenwich day n would be a 1 day by local criteria at Fort Rae and day $n+1$ would be the 2 day.

As an outcome of the discussion of the significance of non-cyclic changes imposed at hours wholly unrelated to local phenomena (§ 37), and the now established local time control over all major aspects of disturbance, it is probably worthy of consideration whether diurnal variations should be formed not for Greenwich days but for local days. The phenomena of the preceding paragraphs gives such a suggestion considerable support.

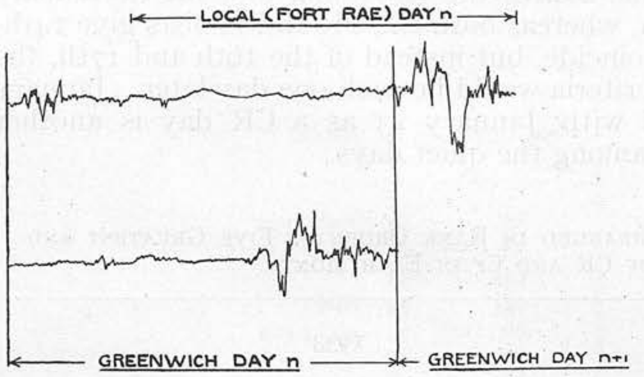


FIG. 14.—Effect of local time variation of disturbance on the characterisation of days according to Greenwich time.

§ 80. *Diurnal variation of irregular disturbance.*—The primary purpose in constructing the hourly range products $Hr_H \,.\, 10^{-4}$ and $Zr_Z \,.\, 10^{-4}$ throughout the 13 months was to provide a practical though only proximate basis by which the daily distribution of disturbance at Fort Rae could be examined. In using these products or their combination $(Hr_H + Zr_Z) \,.\, 10^{-4}$ it was understood that they took account of only one effect of disturbance on the force components of the field, viz. the increased range of the perturbations of comparatively short period: the extent to which the components were simultaneously increased or depressed below their average values, which is an equally prominent characteristic of another aspect of disturbance, has been dealt with at an earlier stage in this discussion. Further, the use of the first power of the range would certainly be an unjustifiable simplification if a rigorous measure of the distribution of disturbance energy through the day were wanted. At best, all that the daily disturbance variations deduced from the present data can give is the average distribution of hours of greater and less liability to perturbations of duration of the order of one hour. For this purpose the simple hourly ranges (r_H, r_Z) of the two force components in the meridian would have been adequate for Fort Rae alone, but for comparison with similar data from other stations the products of the ranges with the mean values of the components of the field in which the ranges are produced have been recommended for general use.

For reasons which have been explained in § 72 the hourly ranges in declination have more recently been measured, and the diurnal variations in r_D have been considered along with those from H and Z.

Tables 76 and 77 give the monthly mean values of $Hr_H \,.\, 10^{-4}$ and $Zr_Z \,.\, 10^{-4}$ for each hour of the day. Table 78 does the same for r_D in minutes of arc. In Table 79 these monthly means are combined into seasons, an additional section (the third in the table) being added to show the seasonal means for the composite product $(Hr_H + Zr_Z) \,.\, 10^{-4}$ derived by combining those for the separate products.

Fig. 15 represents the data of Table 79 rearranged to show the course of the diurnal variation of irregular disturbance in terms of local time. As has been shown (§ 75) r_H and r_Z are of the same order of size; but since Z/H is nearly 8, the variation of irregular disturbance in Z has a range eight times that for H, so that the scale for H in fig. 15 has been made ten times that for Z. And since the equivalent in force transverse to the meridian of one minute of arc in D is 2·25 γ, the scale used for D is approximately the same in force units as that for H.

The striking feature about fig. 15 is the similarity of the variations in all three separate components. This variation of irregular disturbance we shall denote by D_i instead of D, as used in the geographically more extensive discussion given

TABLE 76.—MONTHLY MEAN DIURNAL VARIATION OF $Hr_H \cdot 10^{-4}$ FROM ALL DAYS.
(Mean values for periods of 60 minutes ending at the hours of Greenwich Mean Time: unit 1 γ^2.)

Hour G.M.T.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2
1932 Aug.	49·2	48·3	47·1	51·0	71·1	111·8	173·4	197·5	186·9	157·2	92·4	86·0	86·6	66·3	83·0	81·3	61·3	60·0	53·0	40·7	43·1	38·8	47·1	41·9
Sept.	43·9	39·2	54·1	69·9	88·0	128·7	168·7	192·3	179·9	130·5	89·8	83·2	69·0	98·0	95·3	113·8	103·0	68·4	36·4	36·0	35·4	40·7	47·4	48·2
Oct.	34·0	33·0	28·2	57·7	67·3	73·5	96·6	113·6	95·5	121·0	104·5	101·4	92·6	76·6	73·3	87·3	70·0	50·2	34·6	32·5	35·2	40·4	38·0	35·8
Nov	26·1	27·9	27·3	30·2	50·7	76·1	119·7	134·8	128·5	93·4	79·0	85·9	82·5	85·0	72·5	67·2	49·0	52·0	39·6	43·4	34·9	36·0	32·4	26·7
Dec.	39·6	39·8	35·0	42·8	39·6	45·5	70·2	122·1	156·7	112·6	116·5	79·4	80·7	91·1	83·2	70·3	58·5	70·7	55·6	51·2	46·4	51·0	38·5	38·5
1933 Jan.	40·3	45·4	41·9	44·9	44·5	73·2	58·7	105·8	124·7	125·6	81·9	67·4	69·5	72·6	84·3	76·4	67·7	65·4	55·4	46·9	53·4	55·0	56·2	40·9
Feb.	45·6	38·3	56·5	66·1	58·3	70·5	71·0	115·1	132·3	127·9	115·6	96·3	85·1	71·0	78·8	77·5	61·6	58·9	52·5	51·3	42·0	46·2	50·1	43·6
Mar.	39·7	44·5	48·5	66·1	64·4	119·5	95·5	123·2	132·6	148·1	110·2	110·8	85·6	69·9	86·5	79·9	67·9	50·2	46·1	39·2	42·6	43·5	45·3	48·7
Apr.	57·1	44·0	52·1	53·8	75·5	149·9	164·8	174·3	173·6	121·8	102·9	93·1	108·4	104·1	81·0	72·7	73·1	61·0	38·1	47·3	43·2	52·3	62·7	51·3
May	47·9	49·0	45·9	47·0	60·9	103·6	138·8	128·2	124·4	97·7	89·2	66·3	68·5	77·6	87·1	83·7	56·6	46·2	53·7	48·5	35·2	39·8	50·3	55·3
June	51·3	48·1	64·4	47·5	61·2	70·3	118·9	136·5	135·2	90·5	91·6	66·0	71·3	68·3	68·7	58·0	46·3	39·9	25·7	26·7	30·4	40·1	42·4	46·9
July	46·8	45·7	42·3	41·2	54·8	52·0	86·6	139·2	94·7	125·3	89·2	78·4	81·0	78·7	70·0	73·7	50·0	35·8	27·2	25·4	26·1	28·4	39·3	41·7
Aug.	39·5	31·4	39·0	35·2	53·6	111·5	150·5	157·0	155·6	119·2	77·9	72·6	79·7	88·8	64·7	56·1	53·3	53·8	41·5	49·3	40·1	33·0	41·5	42·6

TABLE 77.—MONTHLY MEAN DIURNAL VARIATION OF $Zr_Z \cdot 10^{-4}$ FROM ALL DAYS.
(Mean values for periods of 60 minutes ending at the hours of Greenwich Mean Time: unit 1 γ^2.)

Hour G.M.T.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2
1932 Aug.	199·5	295·7	262·3	304·1	434·2	787·4	1199·3	1412·2	1219·9	944·0	670·5	639·8	547·5	512·6	544·2	578·1	463·1	279·5	237·9	196·8	198·2	183·1	226·2	209·3
Sept.	228·3	296·1	306·0	473·3	569·1	933·5	1314·4	1489·6	1292·0	896·3	704·3	514·1	484·3	597·7	696·6	669·7	558·0	395·5	246·5	145·2	166·7	160·4	185·0	204·2
Oct.	143·1	176·7	186·5	382·7	425·1	574·2	991·7	1055·1	954·5	864·5	680·4	677·5	572·4	606·5	587·0	609·4	403·7	221·0	161·9	161·7	174·9	149·6	132·2	158·7
Nov.	110·6	125·1	148·9	185·3	273·7	565·6	920·2	1123·4	953·1	693·6	503·6	436·9	487·0	519·4	468·0	431·2	291·8	245·3	185·0	188·3	134·8	136·8	151·3	118·3
Dec.	186·1	229·0	181·4	316·9	269·6	287·9	469·2	947·2	1175·3	887·1	674·0	451·0	479·3	586·7	549·7	429·2	304·4	394·2	330·0	222·8	203·8	226·9	181·6	169·6
1933 Jan.	193·9	235·0	269·9	285·7	306·5	533·5	446·1	784·8	1061·8	972·4	541·0	386·5	358·2	419·8	410·1	503·4	462·8	320·2	259·1	270·1	229·9	215·4	224·1	205·4
Feb.	281·2	171·2	266·8	389·4	405·8	513·1	511·7	810·9	938·5	1059·5	682·1	569·2	488·0	549·4	463·4	485·5	503·5	335·7	295·8	273·9	211·4	231·4	248·3	225·0
Mar.	230·1	325·8	378·6	455·0	472·3	723·8	767·6	1041·4	1107·8	921·8	787·8	573·3	523·2	443·3	539·8	476·1	379·2	325·4	226·2	186·2	276·4	183·2	208·7	303·5
Apr.	305·2	307·2	403·6	353·3	476·3	973·7	1049·7	1231·5	1203·1	924·4	754·1	487·4	574·3	656·7	559·7	543·5	452·7	227·9	150·9	173·7	202·1	261·3	311·2	295·1
May	272·1	264·3	288·4	290·4	375·6	625·6	1052·6	869·4	1066·6	713·6	606·9	489·2	431·1	571·0	539·9	435·0	406·5	216·7	223·4	258·4	172·1	217·8	196·9	270·8
June	350·6	377·0	426·2	389·4	444·3	475·5	852·1	1081·4	938·0	689·7	569·2	572·5	578·3	509·3	492·2	371·5	272·1	127·8	105·0	118·0	125·6	144·3	179·0	210·4
July	188·8	235·9	278·5	291·5	386·5	392·2	675·5	1106·9	661·1	784·7	550·3	472·3	538·5	497·7	450·6	360·7	236·0	161·2	95·4	91·6	91·2	97·5	112·7	154·2
Aug.	155·0	176·9	188·1	256·8	313·5	744·9	1211·5	1257·1	1007·9	863·0	438·2	501·5	430·9	664·0	488·2	325·4	398·2	292·3	183·7	238·3	149·1	137·2	139·1	133·7

TABLE 78.—MONTHLY MEAN DIURNAL VARIATION OF DECLINATION HOURLY RANGE (r_D) FROM ALL DAYS.
(Mean values for periods of 60 minutes ending at the hours of Greenwich Mean Time: unit 1 minute of arc.)

Hour G.M.T.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
1932 Aug.	12·0	16·0	17·7	17·8	25·3	39·4	61·7	75·2	50·8	46·0	40·0	34·6	32·9	27·7	34·8	33·8	31·8	27·4	26·6	20·2	22·1	14·6	13·4	11·3
Sept.	12·6	14·3	16·0	19·8	26·1	46·7	66·3	64·0	70·1	49·1	35·6	32·4	23·2	38·9	45·0	46·1	35·6	28·7	25·5	17·1	15·7	12·2	12·0	12·5
Oct.	8·4	8·0	8·3	24·3	26·8	35·4	40·1	52·7	46·1	49·1	38·0	36·1	37·0	30·9	37·8	32·8	27·8	18·3	17·2	14·9	12·6	10·1	10·5	9·0
Nov.	5·6	6·0	6·9	10·4	14·9	31·8	45·8	56·5	52·3	32·4	26·4	26·6	27·9	31·9	31·3	27·8	20·9	18·3	17·6	16·7	10·5	8·4	8·4	6·5
Dec.	8·0	8·3	8·7	15·2	12·9	15·0	26·7	48·0	66·9	47·4	36·7	25·6	27·8	34·0	29·3	27·9	22·0	28·3	19·9	15·3	12·6	12·2	9·9	8·4
1933 Jan.	9·2	9·8	10·7	12·0	15·1	29·8	26·6	42·8	58·7	49·3	31·0	19·4	20·6	21·0	25·7	30·2	27·0	25·6	17·7	18·6	14·6	13·0	11·8	10·6
Feb.	12·8	9·8	12·7	19·3	19·6	27·9	28·3	41·3	45·7	42·2	36·1	30·4	24·3	28·9	30·8	31·3	27·3	23·1	22·3	20·5	15·5	14·3	12·5	12·2
Mar.	13·3	17·0	14·9	23·3	20·5	40·2	36·6	52·6	49·2	43·8	40·9	31·2	26·9	24·8	33·2	29·9	30·6	24·8	22·0	18·8	16·0	15·7	11·9	14·6
Apr.	15·2	13·5	17·6	15·4	34·3	48·4	56·6	61·6	55·2	47·5	40·1	32·2	30·7	30·8	28·8	31·7	32·5	26·6	21·7	21·1	18·2	16·0	14·6	13·9
May	12·1	13·3	15·0	14·1	22·3	27·4	50·5	47·1	45·0	40·5	27·8	24·5	29·7	33·4	29·0	29·6	24·0	25·7	25·8	21·0	13·8	16·0	14·2	12·2
June	14·4	14·8	19·0	18·8	19·5	22·5	35·4	44·1	38·5	30·7	27·9	24·5	24·7	31·5	23·8	21·9	19·2	17·1	14·7	15·1	12·8	12·2	11·4	10·2
July	9·4	10·9	12·8	11·9	15·4	17·1	28·8	44·3	28·8	31·8	27·8	24·0	25·9	27·9	24·5	27·2	18·6	18·2	16·1	15·4	14·4	10·5	11·0	9·6
Aug.	8·6	8·9	11·3	9·3	17·0	37·1	66·6	50·2	51·0	41·6	23·2	23·1	23·7	32·0	36·9	22·9	26·1	24·5	19·7	25·7	13·8	11·0	8·9	9·0

TABLE 79.—SEASONAL MEAN DIURNAL VARIATION OF $Hr_H . 10^{-4}$, $Zr_Z . 10^{-4}$, Cr, AND r_D ON ALL DAYS: UNIT 1 γ^2.
(Mean values for periods of 60 minutes ending at the hours of Greenwich Mean Time.)

Hour G.M.T.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
												$Hr_H . 10^{-4}$.												
	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2
w . .	37·9	37·8	40·2	46·0	48·3	66·3	79·9	119·5	**135·5**	114·9	98·3	82·3	79·5	79·9	79·7	72·9	59·2	61·7	50·8	48·2	44·2	47·1	44·3	*37·4*
e . .	43·7	40·2	45·7	61·9	73·8	117·9	131·4	**150·9**	145·4	130·3	101·9	97·1	88·9	87·1	84·0	88·4	78·5	57·5	38·8	*38·7*	39·1	44·2	48·3	46·0
s . .	47·6	45·7	48·9	44·7	59·8	84·4	126·5	**145·3**	131·4	112·9	88·8	72·5	76·0	75·5	74·9	71·0	52·5	44·7	38·5	36·4	*33·3*	36·1	44·1	46·5
y . .	43·1	41·2	44·9	50·9	60·6	89·5	112·6	**138·5**	137·5	119·4	96·3	84·0	81·4	80·9	79·5	77·4	63·4	54·6	42·7	41·1	*38·9*	42·4	45·6	43·3
												$Zr_Z . 10^{-4}$.												
	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2
w . .	192·9	190·1	216·7	294·3	313·9	475·0	586·8	916·6	**1032·2**	903·1	600·2	460·9	453·1	518·8	472·8	462·3	390·6	323·9	267·5	238·8	195·0	202·6	201·3	*179·6*
e . .	226·7	276·5	318·7	416·1	485·7	801·3	1030·9	**1204·4**	1139·3	901·7	731·7	563·1	538·5	576·1	595·8	574·7	448·4	292·5	196·4	*166·7*	205·0	188·6	209·3	240·4
s . .	247·2	278·4	304·6	312·9	395·1	564·9	946·4	**1098·1**	944·9	772·9	570·2	526·2	509·3	541·6	499·7	404·7	336·3	197·9	158·7	171·4	*140·7*	154·9	167·8	201·7
y . .	222·3	248·3	280·0	341·1	398·2	613·7	854·7	**1073·0**	1038·8	859·3	634·0	516·7	500·3	545·5	522·8	480·6	391·8	271·4	207·5	192·3	*180·2*	182·1	192·8	207·2
												$Cr = (Hr_H + Zr_Z) . 10^{-4}$.												
	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2
w . .	230·8	227·9	256·9	340·3	362·2	541·3	666·7	1036·1	**1167·7**	1018·0	698·5	543·2	532·6	598·7	552·5	535·2	449·8	385·6	318·3	287·0	239·2	249·7	245·6	*217·0*
e . .	270·4	316·7	364·4	478·0	559·5	919·2	1162·5	**1355·3**	1284·7	1032·0	833·6	660·2	627·4	663·2	679·8	663·1	526·9	350·0	235·2	*205·4*	244·1	232·8	257·6	286·4
s . .	294·8	324·1	353·5	357·6	454·9	649·3	1072·9	**1243·4**	1076·3	885·8	659·0	598·7	585·3	617·1	574·6	475·7	388·8	242·6	197·2	207·8	*174·0*	191·0	211·9	248·2
y . .	265·4	289·5	324·9	392·0	458·8	703·2	967·3	**1211·5**	1176·3	978·7	730·3	600·7	581·7	626·4	602·3	558·0	455·2	326·0	250·2	233·4	*219·1*	224·5	238·4	250·5
												r_D in minutes of arc.												
	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
w . .	8·9	*8·5*	9·7	14·2	15·6	26·1	31·9	47·1	**55·9**	42·8	32·5	25·5	25·1	28·9	29·3	29·3	24·3	23·9	19·4	17·8	13·3	12·0	10·7	9·4
e . .	12·4	13·2	14·2	20·7	26·9	42·7	49·9	**57·7**	55·1	47·4	38·7	33·0	29·5	31·3	36·2	35·1	31·6	24·6	21·6	18·0	15·6	13·5	*12·3*	12·5
s . .	11·5	12·9	15·3	14·6	19·6	26·3	44·7	**49·5**	40·8	36·7	28·8	25·5	27·1	30·7	28·3	26·5	22·7	21·7	19·9	18·6	14·7	12·9	11·9	*10·5*
y . .	10·9	11·5	13·1	16·5	20·7	31·7	42·1	**51·5**	50·6	42·3	33·3	28·0	27·3	30·3	31·3	30·4	26·2	23·4	20·3	18·1	14·5	12·8	11·6	*10·8*

in *Proceedings of the Royal Society*, A, **149**, pp. 298–311 (1935), in which declination was not considered.

Comparison of the curves of fig. 15 with those of fig. 6, illustrating the ordinary regular variation on all days, shows that D_i bears no obvious relation to the regular variation formed from the hourly departures of these components from their mean values. In the case of H and Z the latter are in the main almost opposite in phase, but the corresponding trends in D_i for H and Z are strictly similar: r_D also follows an exactly similar course, though the regular variation in declination is itself different from that of either H or Z or D_i. It must therefore be inferred that the diurnal phenomena illustrated by fig. 15 are common to all elements at Fort Rae, that they are roughly constant in form throughout the year, and that they represent one aspect of the activity of the disturbance field to which the main contribution is made by the short period perturbations measured by r.

§ 81. *Relation of* D_i *to the time differentials of the force vectors.*—Since the regular diurnal variation at Fort Rae has a range of over 100 γ on all days and may be as high as 300 γ on disturbed days, it is natural to infer that the hour-to-hour change in the mean values of the components will contribute to the form of D_i, based as it is on the extreme hourly ranges. But though it is clear that D_i cannot be related to the time differentials of those regular variations for *both* H and Z, it is instructive to consider what relationship may exist with the differential curve from one or other of them. This has been done by subtracting from each hourly constituent of the annual mean inequalities for both all and disturbed days the value of the preceding hour and plotting the hour-to-hour numerical differences as in fig. 16. This figure shows that whereas there is no relation between the H differential curves and D_i for that element, the Z differentials, especially those derived from the smoother variation for all days, closely reproduces the main features of D_i (Z).

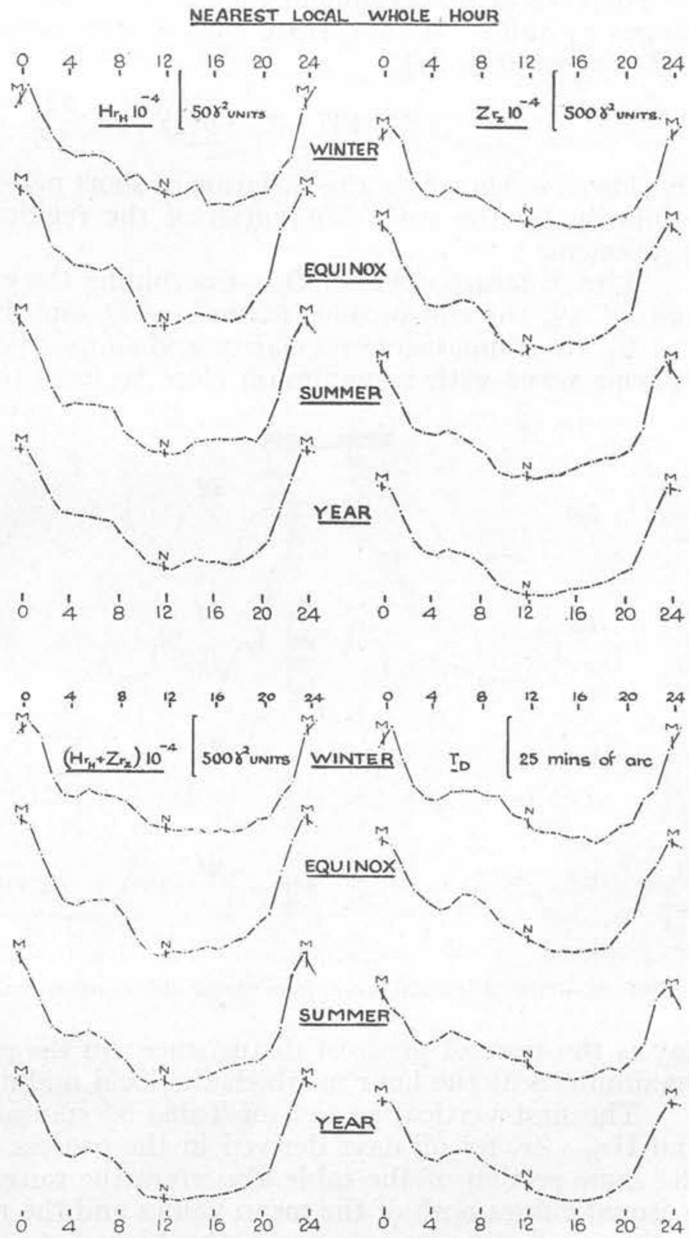


FIG. 15.—Diurnal variations Hr_H, Zr_Z, r_D, and $Hr_H + Zr_Z$.

This result, at first sight surprising, may have its explanation in the following considerations: D_i is primarily a measure of short period oscillations which, on other grounds, may be largely attributed to localised earth currents. The generation of such currents may be regarded as dependent on the rate of change of those primary electric currents in the atmosphere which are responsible for the major features of disturbance. Now an accessible measure of such rates of current change is available in the corresponding changes in the energy of the associated magnetic field. If the vectors H and Z of this field become $H+\Delta H$ and $Z+\Delta Z$ the energy change will be measured by $H.\Delta H+Z.\Delta Z$ when the contribution of second order terms is neglected. In this expression the vector changes ΔH and ΔZ should be strictly synchronous, but for purposes of this argument they may be assumed to be represented by the hourly ranges r_H and r_Z so that, since r_H/r_Z is approximately unity (§ 75) and at Fort Rae $H/Z \simeq 7700/60000 \simeq \frac{1}{8}$,

$$H.\Delta H+Z.\Delta Z=Z.\Delta Z\left(\frac{\Delta H}{\Delta Z}.\frac{H}{Z}+1\right)\doteqdot\frac{9}{8}Z.\Delta Z.$$

On this view, therefore, the variation of short period irregular disturbance is controlled primarily by the time differential of the regular diurnal variation in the vertical component.

§ 82. *Characteristics of* D_i.—Continuing the examination of the data of Table 79 and fig. 15, the conspicuous features of D_i may be summarised as follows:—

(i) Its comparative regularity and simplicity of form. It is essentially a single 24-hour wave with a maximum close to local midnight and minimum about local noon. These general characteristics remain constant throughout the year.

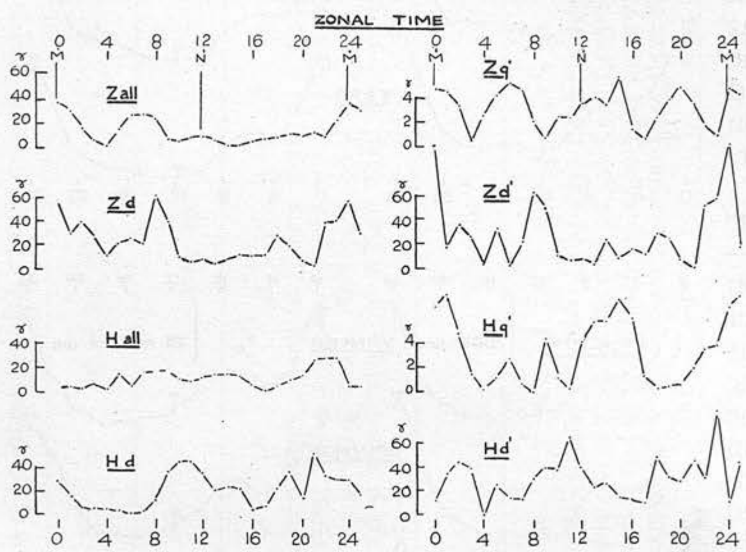


FIG. 16.—Time differential curves from regular diurnal variations.

(ii) The rise in the late evening hours after 21h is invariably steep: the fall off in the scale of irregular disturbance after midnight is almost equally steep for the first three or four hours after which it is arrested. The tendency to a recrudescence of disturbance in the local morning (4–8h) is equally prominent in H and Z, is least prominent in winter, and more prominent in the equinoctial than the summer months.

(iii) In winter in both H and Z the first hour of the local day is the time of greatest disturbance: in the equinoctial and summer months the maximum is at the hour in which the local midnight falls.

The first vertical section of Table 80 summarises the mean values of Hr_H, Zr_Z, and Hr_H+Zr_Z for all days derived in the process of forming D_i for these quantities: the same section of the table also gives the range of D_i. A feature of the separate seasonal values both of the mean values and the ranges from these all day variations is the small difference between the highest (equinox) and lowest (winter) values. The characteristics of disturbance represented by these data (viz. the average values of the hourly range and the relative concentrations of high ranges near midnight and low ranges near noon) are remarkably constant throughout the year.

§ 83. D_i *on selected quiet and disturbed days*.—To see how far the features of D_i found for the average of all days are common to, or are modified by, the general degree of disturbance obtaining on particular days, variations similar to those in Table 79 have been constructed for the set of 38 quietest q' days and 40 most disturbed d' days already selected for other purposes. The results are given in Tables 81 and 82 and plotted in fig. 17.

On the broad view, D_i on both q' and d' days reproduces the features seen on all days. As is shown by the lower half of Table 80, the difference in scale is naturally very great. Taking the composite $Hr_H + Zr_Z$ in the bottom line of that table, the range in D_i is 165 γ^2 for q' days, 992 γ^2 for all days, and 2159 γ^2 for d' days; and in distinction from the all day data both the separate mean values of Hr_H and Zr_Z (and therefore of $Hr_H + Zr_Z$) and the range of their diurnal variations are invariably greatest in summer and least in winter, but with certain reservations the form of the variation D_i remains sensibly constant. (It should be mentioned here that the apparent numerical disagreement between the sums of the separate ranges for the diurnal variations of Hr_H and Zr_Z, and the range of the diurnal variation of their combination $Hr_H + Zr_Z$, arises solely from the slight variability in incidence of times of maxima and minima of the two constituent variations in some seasons in the comparatively limited groups of q' and d' days.)

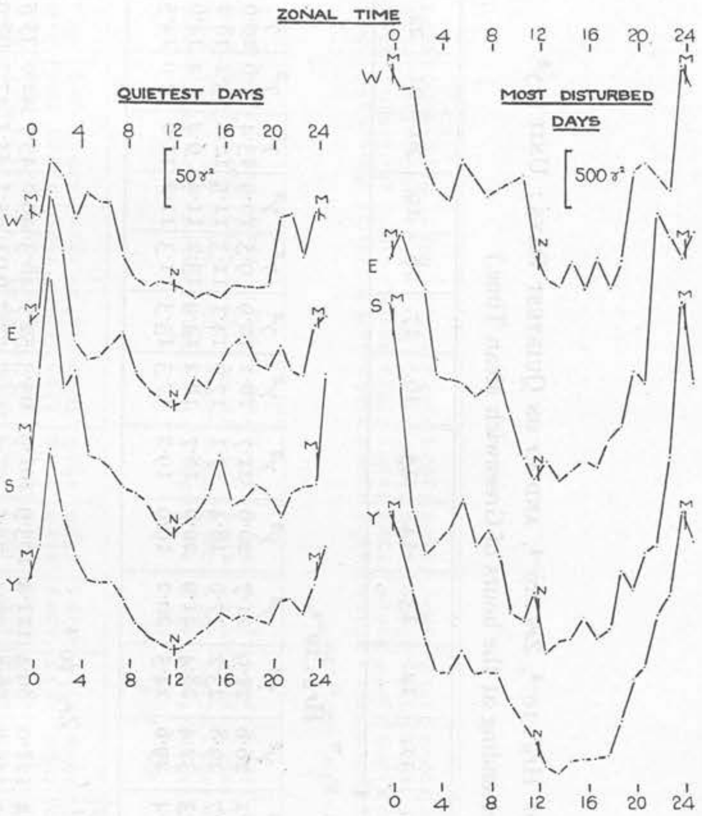


FIG. 17.—Diurnal variation of irregular disturbance on q' and d' days.

Of the reservations just mentioned the most important relates to the times of incidence of the maxima and minima. For the complete set of d' days the maximum falls at 7–8h G.M.T. (local mean midnight 7h 44m G.M.T.) and the minimum at 21–22h G.M.T., the former coinciding with, and the latter being one hour behind, the corresponding times for all days. But on the average of the 38 q' days, the maximum is at 9–10h G.M.T. and the minimum 19–20h. Now a scatter in the times of incidence of the minima is to be expected, since the rate of change of the range is slow in the hours about, and especially immediately following, local

TABLE 80.—MEAN VALUES OF $Hr_H . 10^{-4}$, $Zr_Z . 10^{-4}$, AND Cr, AND RANGE OF D_i FOR THESE QUANTITIES DERIVED IN CONJUNCTION WITH TABLES 79, 81, AND 82.

	All Days.				Quietest Days.				Most Disturbed Days.			
	w.	*e.*	*s.*	*y.*	*w.*	*e.*	*s.*	*y.*	*w.*	*e.*	*s.*	*y.*
Mean value:—	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2
$Hr_H . 10^{-4}$ . .	67·2	77·6	68·3	71·2	14·3	17·2	19·3	16·7	163·2	163·7	176·4	167·1
$Zr_Z . 10^{-4}$ . .	420·4	513·7	435·3	456·4	72·7	86·1	87·4	82·1	1139·6	1145·1	1181·1	1155·3
$(Hr_H + Zr_Z) . 10^{-4}$	487·6	591·3	503·6	527·6	87·0	103·3	106·7	98·8	1302·8	1308·8	1357·5	1322·4
D_i range:—												
$Hr_H . 10^{-4}$ . .	98·1	112·2	112·0	99·6	19·0	21·5	24·9	18·4	214·9	248·7	364·9	254·9
$Zr_Z . 10^{-4}$ . .	852·6	1037·7	957·4	892·8	106·9	156·1	192·7	148·5	1650·3	1979·1	2541·3	1904·0
$(Hr_H + Zr_Z) . 10^{-4}$	950·7	1149·9	1069·4	992·4	114·4	176·7	217·6	165·3	1859·3	2216·3	2906·2	2158·9

TABLE 81.—SEASONAL MEAN DIURNAL VARIATION OF $Hr_H \cdot 10^{-4}$, $Zr_Z \cdot 10^{-4}$, AND Cr ON QUIETEST DAYS: UNIT 1 γ^2.

(Mean values for periods of 60 minutes ending at the hours of Greenwich Mean Time.)

Hour G.M.T.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
	$Hr_H \cdot 10^{-4}$.																							
	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2
w . .	8·9	10·4	10·3	10·4	12·0	14·9	12·0	15·8	17·2	18·1	**26·6**	21·9	21·7	20·6	21·7	16·1	10·9	9·5	10·9	13·4	11·6	10·6	10·6	*7·6*
e . .	22·2	20·6	15·8	*11·2*	15·6	12·0	12·0	17·7	15·5	**32·7**	29·8	23·2	17·0	18·4	17·1	17·6	14·1	11·3	11·5	12·1	13·1	18·2	16·4	17·3
s . .	19·2	18·4	18·1	13·5	12·6	12·0	14·3	10·6	22·4	**34·3**	32·4	28·4	21·9	20·6	18·7	18·2	14·9	13·2	11·4	*9·4*	11·4	14·6	26·6	25·4
y . .	16·8	16·5	14·7	11·7	13·4	13·0	12·8	14·7	18·4	28·4	**29·6**	24·5	20·2	19·9	19·2	17·3	13·3	11·3	*11·2*	11·6	12·0	14·5	17·9	16·8
	$Zr_Z \cdot 10^{-4}$.																							
w . .	48·1	47·4	46·6	48·0	101·5	100·9	68·6	101·9	95·2	**142·4**	121·0	89·4	111·4	103·9	101·9	65·3	52·7	46·3	49·8	45·7	42·0	*35·5*	40·1	39·5
e . .	84·2	92·9	75·6	78·1	91·5	76·7	71·4	105·1	116·5	**201·2**	156·8	86·8	79·4	79·5	91·5	101·7	72·7	61·1	55·1	*45·1*	47·7	63·9	56·5	75·5
s . .	58·9	63·1	75·5	71·4	54·4	75·2	77·1	81·7	161·9	**235·6**	139·8	158·9	95·7	94·9	87·0	73·1	71·4	65·9	49·1	*42·9*	49·0	53·4	68·2	92·9
y . .	63·7	67·8	65·9	65·8	82·5	84·3	72·4	96·2	124·5	**193·1**	139·2	111·7	95·5	92·8	93·5	80·0	65·6	57·8	51·3	*44·6*	46·2	50·9	54·9	69·3
	$Cr = (Hr_H + Zr_Z) \cdot 10^{-4}$.																							
w . .	57·0	57·8	56·9	58·4	113·5	115·8	80·6	117·7	112·4	**160·5**	147·6	111·3	133·1	124·5	123·6	81·4	63·6	55·8	60·7	59·1	53·6	*46·1*	50·7	47·1
e . .	106·4	113·5	91·4	89·3	107·1	88·7	83·4	122·8	132·0	**233·9**	186·6	110·0	96·4	97·9	108·6	119·3	86·8	72·4	66·6	*57·2*	60·8	82·1	72·9	92·8
s . .	78·1	81·5	93·6	84·9	67·0	87·2	91·4	92·3	184·3	**269·9**	172·2	187·3	117·6	115·5	105·7	91·3	86·3	79·1	60·5	*52·3*	60·4	68·0	94·8	118·3
y . .	80·5	84·3	80·6	77·5	95·9	97·3	85·2	110·9	142·9	**221·5**	168·8	136·2	115·7	112·7	112·7	97·3	78·9	69·1	62·5	*56·2*	58·2	65·4	72·8	86·1

TABLE 82.—SEASONAL MEAN DIURNAL VARIATION OF $Hr_H . 10^{-4}$, $Zr_Z . 10^{-4}$, AND Cr ON MOST DISTURBED DAYS: UNIT 1 γ^2.

(Mean values for periods of 60 minutes ending at the hours of Greenwich Mean Time.)

Hour, G.M.T.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
												$Hr_H . 10^{-4}$.												
	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2	γ^2
w	113·4	85·9	136·0	204·9	173·9	152·1	159·9	**307·7**	295·9	192·3	181·7	179·0	138·4	124·1	196·7	169·9	172·6	191·9	166·4	154·2	113·6	*92·8*	115·7	98·7
e	96·1	86·4	106·7	175·9	154·0	**324·8**	288·1	279·7	295·9	276·7	211·8	158·6	159·2	162·1	143·6	166·6	177·0	142·2	95·0	86·5	87·7	87·6	89·9	*76·1*
s	90·7	100·8	138·7	110·2	180·2	185·0	291·4	**442·5**	397·2	261·5	148·2	169·2	223·5	150·3	214·8	202·9	135·5	140·6	150·9	139·5	*77·6*	84·8	98·1	105·0
y	100·1	91·0	127·1	163·7	169·4	220·6	246·5	**343·3**	329·7	243·5	180·6	168·9	173·7	145·5	185·0	179·8	161·7	158·2	137·4	126·7	92·9	*88·4*	101·2	93·2
												$Zr_Z . 10^{-4}$.												
w	691·7	477·1	658·7	1318·3	1416·4	1321·9	1193·3	**2090·7**	1891·9	2016·0	1406·6	1183·0	1124·0	1487·9	1249·4	1134·3	1193·6	1224·9	1314·7	832·3	525·0	487·4	671·4	*440·4*
e	487·9	718·1	813·8	1212·1	1122·7	**2357·0**	2209·7	2021·3	2207·9	1987·3	1835·1	1182·3	1148·6	1101·9	1035·8	1071·9	1208·4	859·2	564·6	397·7	548·4	*377·9*	459·8	552·6
s	574·9	637·3	1106·5	944·2	1218·8	1258·5	1873·2	**2994·2**	2382·5	1461·1	1213·5	1298·7	1351·8	1673·7	1216·4	1365·2	1218·2	746·6	653·5	890·2	*452·9*	528·8	557·2	728·2
y	584·8	610·8	859·7	1158·2	1252·6	1645·8	1758·7	**2368·7**	2160·8	1821·5	1485·1	1221·3	1208·1	1421·2	1167·2	1190·5	1206·7	943·6	844·3	706·7	508·8	*464·7*	562·8	573·7
												$Cr = (Hr_H + Zr_Z) . 10^{-4}$.												
w	805·1	563·0	794·7	1523·2	1590·3	1474·0	1353·2	**2398·4**	2187·8	2208·3	1588·3	1362·0	1262·4	1612·0	1446·1	1304·2	1366·2	1416·8	1481·1	986·5	638·6	580·2	787·1	*539·1*
e	584·0	804·5	920·5	1388·0	1276·7	**2681·8**	2497·8	2301·0	2503·8	2264·0	2046·9	1340·9	1307·8	1264·0	1179·4	1238·5	1385·4	1001·4	659·6	484·2	636·1	*465·5*	549·7	628·7
s	665·6	738·1	1245·2	1054·4	1399·0	1443·5	2164·6	**3436·7**	2779·7	1722·6	1361·7	1467·9	1575·3	1824·0	1431·2	1568·1	1353·7	887·2	804·4	1029·7	*530·5*	613·6	655·3	833·2
y	684·9	701·8	986·8	1321·9	1422·0	1866·4	2005·2	**2712·0**	2490·5	2065·0	1665·7	1390·2	1381·8	1566·7	1352·2	1370·3	1368·4	1101·8	981·7	833·4	601·7	*553·1*	664·0	666·9

noon. But the rise to the maximum in the night hours is both isolated and sharp, so that a retardation of two hours from 7–8h G.M.T. on all days and d' days to 9–10h on q' days must be significant, more especially since the first three lines of Table 81 show that the retardation is common to the days of the equinoctial and summer months and is actually increased to three hours in winter.

In view of the relation already found between the time differential of the regular diurnal variation in Z and the form of D_i, some explanation of this q' day feature may be traceable to the behaviour of the former on this class of days. The hour-to-hour differences of the constituents of the Z inequalities for q' and d' days were therefore plotted regardless of sign. The curves so formed (fig. 16) are instructive in showing that, whereas the differential of the d' day inequality reproduces the features of D_i on this set of days, the corresponding q' days' curve is of a wholly different type. (Apart from the present purpose, this distinction is illuminating in that it confirms conclusions already drawn (§ 46) about the difference in form of the regular diurnal variations on those two contrasting types of days.) It will be noted that the differential curve of Z for q' days is actually near one of its four minima when the corresponding D_i is a maximum. Therefore, since the peculiarity of the q' day retardation of maximum is not explainable in terms of the ordinary hour-to-hour changes on this set of days, and since, moreover, it is a feature of all seasons, it must be inferred that short period disturbance on quietest days at Fort Rae tends on the average to be most pronounced two hours after local midnight, and therefore two hours later than on disturbed days.

§ 84. *Harmonic analysis of* D_i.—After the application of non-cyclic corrections to the diurnal variation data of $(Hr_H + Zr_Z) \,.\, 10^{-4}$ set out in Tables 79 and 81 for all, q', and d' days, the variations were analysed harmonically to determine the amplitudes (A_1, A_2) and the phases (P_1, P_2) of their 24-hour and 12-hour component waves. The results are shown in Table 83. It is to be noted that the amplitudes given here for all days differ by a factor of 2 from those already published in connection with an extensive inquiry into the characteristics of D_i.* In that inquiry the composite hourly values of $(Hr_H + Zr_Z) \,.\, 10^{-4}$ were inadvertently halved. Since the same procedure was carried out for the Godhavn data in Table II of that paper, the conclusions there drawn are not affected.

The results of the analysis shown in Table 83 serve to confirm more rigorously the inferences already made regarding the characteristics of D_i on all, q', and d' days. In particular, it becomes clear that the chief contributor to the retardation of the principal maximum on q' days is the semi-diurnal wave. On the average of all days, the maximum of that wave falls exactly at midnight; on d' days it falls one hour earlier, but on q' days the corresponding maximum is two to three hours after midnight. In contrast, the times of maximum of the 24-hour wave for the first two classes are at 1·5 hours after midnight, with the q' day maximum only 0·3 hours behind that time. Hence if the 24-hour wave does not completely overwhelm the semi-diurnal wave in amplitude, it is to be expected that on q' days the resultant maximum should be retarded two to three hours behind the corresponding times for all and d' days. The ratios A_2/A_1 in the final column of Table 83 show that at least in the equinoctial and summer months the conditions for this are favourable, since A_2 then is not less than 50% of A_1.

Before leaving Table 83 it should be noted that the comparative steadiness of the A_2/A_1 ratios throughout the subdivisions of all and d' days, and to a less extent q' days, is a further confirmation of the persistence in type of D_i. The only serious scatter in the values of the ratio occurs in q' days, and since these are derived from a maximum of 14 days per season, selected explicitly for their low values of $Hr_H + Zr_Z$, it is not surprising that the seasonal ratios vary abnormally in this class of days.

§ 85. *Local character figures*.—In the monthly tables in Vol. II, showing details of the maxima and minima in each element, a column gives the local character figure 0, 1, or 2 according to the nature of the records for the three elements. In assigning

* London, *Proc. Roy. Soc.*, A, 149, pp. 298–311 (1935).

these figures all the curves were first examined to obtain a standard of judgment for each of the elements separately. Then covering up part of the record to leave exposed only one element, a figure was allotted to each day. Border line cases were marked with a "+" or a "−" to indicate that that particular element was considered to be slightly more or slightly less disturbed than the figure which had been assigned indicated. All the records were gone through in this way, treating each element independently. Finally, the three figures for each day were compared and a composite figure assigned on the basis of a majority. Generally the figures for H and Z were given more weight than those for D. In cases of doubt the record was re-examined, with all three elements simultaneously exposed.

TABLE 83.—HARMONIC COEFFICIENTS FROM ANALYSIS OF D_r.

Season.	A_1.	P_1.	Equivalent Local Time of Maximum of P_1.	A_2.	P_2.	Equivalent Local Time of Maximum of P_2.	A_2/A_1.
			All Days.				
	γ^2	°	h	γ^2	°	h	
w	319·3	301·8	2·1	130·9	205·9	0·4	0·41
e	431·4	314·7	1·3	138·7	231·1	23·6	0·32
s	373·6	316·3	1·2	107·8	217·2	0·0	0·29
y	372·7	311·6	1·5	123·5	218·4	0·0	0·33
			Quietest Days.				
w	45·3	297·7	2·4	7·2	119·9	3·3	0·16
e	31·0	303·5	2·0	20·5	129·4	2·9	0·66
s	58·1	315·9	1·2	30·1	116·2	3·4	0·51
y	44·4	306·9	1·8	19·2	121·2	3·2	0·43
			Most Disturbed Days.				
w	582·5	358·9	22·4	270·0	255·0	22·8	0·46
e	836·2	318·3	1·0	337·3	245·2	23·1	0·41
s	783·7	312·7	1·4	253·8	248·4	23·0	0·32
y	728·5	311·6	1·5	286·3	249·3	23·0	0·39

This process of assignment of local characters was carried out in two stages. Figures were allocated at one examination to the period August 1932 to June 1933. When the figures for July and August were assigned, the standard used in the earlier batch of records was re-established by a retrospective examination. Finally, all the records were gone through at one examination to ensure a uniformity of standard.

The mean values of the local character figures and the distribution of the 0's, 1's, and 2's are given for each month in Table 84, together with the international figures.

§ 86. *Rank order of months in disturbance by various criteria.*—Regarding C*r* as defined in § 72 as an index of disturbance, it is of interest to examine how the 13 months of the Polar Year arrange themselves in rank order by the various criteria now available. In such an examination it is assumed that the four days of April for which CR and C*r* data are missing were average days in that month. Table 85 shows the months in order of decreasing disturbance as arranged by the criteria indicated in the column headings. The international and local character figures will be denoted by IC and LC.

All four criteria agree in making September 1932 and April 1933 the two most disturbed months; but whereas the international character figures make April more disturbed than September, all three of the local criteria invert the order.

There is no occasion of agreement in all four criteria.

TABLE 84.—CHARACTER FIGURES, LOCAL AND INTERNATIONAL.

	1932.					1933.								Mean.
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	
Mean local character figure	1·16	1·23	1·00	0·90	1·00	0·87	1·07	1·03	1·23	1·06	1·03	1·03	0·97	1·045
Number of local 0 days	3	3	7	6	3	7	6	6	1	3	2	1	7	4·2
,, ,, 1 days	20	17	17	21	25	21	14	18	21	23	25	28	18	20·6
,, ,, 2 days	8	10	7	3	3	3	8	7	8	5	3	2	6	5·6
Mean international character figure.	0·67	0·73	0·73	0·58	0·67	0·65	0·65	0·71	0·76	0·62	0·55	0·54	0·60	0·651

In addition to the placing of September 1932 and April 1933 by the local criteria, the only other occasions in which any three criteria agree occur when the local criteria give December 10th place and when they give November 12th place.

The number of double agreements in place position by the various criteria are as follows:—

Criteria.	No. of Agreements.
IC–LC	0
IC–CR	0
IC–C*r*	2
LC–CR	5
LC–C*r*	5
CR–C*r*	4

That the number of agreements in monthly placings is small is perhaps not surprising, for the reason that the range of difference between the most and least disturbed months is itself comparatively small, especially for the character figures. The greatest of the monthly means of IC (April 1933) was only 0·76, and the least (July 1933) 0·54; the greatest and least values of LC were 1·23 and 0·87 for April and January respectively. It is this evenness together with localised disturbance at Fort Rae, represented by LC but not IC, which gives such diverse placings as 7th to January by IC but only 13th by LC.

To summarise the information of Table 85 and obtain composite rank orders based on the local criteria alone, and on all four criteria together, account was taken of the sums of the numbers representing the rank orders of the individual months by the various local criteria as shown in the first four columns of Table 85A. Each month of a pair with the same rank order by any one criterion in this table was credited with one-half the value of this rank and the next lower rank. Since the four criteria were equally weighted, the last two columns of Table 85A, which show the placings of the months by the combined local criteria and all four criteria, differ at most by one place. But comparison of the rank order by the combined local criteria and that derived from the international character figures alone (column 2) shows that such large differences in placing as already mentioned for January are liable to occur at any time of year. The deduction from this is that local disturbance near the auroral zone is not confined to any one season.

§ 87. *Interdiurnal variability of* H *and* Z : *Monthly* U *activity measures.*—Partly to conform with a recommendation of the International Polar Year Commission

TABLE 85.—RANK ORDER OF MONTHS BY VARIOUS CRITERIA.
(Months arranged in order of decreasing activity.)

Order.	Character Figures.		Range Products.		Composite Rank Order on Basis of Four Criteria.
	International.	Local.	$(HR_H + ZR_Z)$ CR.	$(Hr_H + Zr_Z)$ C*r*.	
1	Apr.	Sept.	Sept.	Sept.	Sept.
2	Sept.	Apr.	Apr.	Apr.	Apr.
3	Oct.	Aug. 1932	Mar.	Aug. 1932	Aug. 1932
4	Mar.	Feb.	Aug. 1932	Mar.	Mar.
5	Aug. 1932	May	June	Oct.	Oct.
6	Dec.	Mar.	Oct.	Feb.	Feb.
7	Jan.	June	Aug. 1933	May	May
8	Feb.	July	May	Aug. 1933	June
9	May	Oct.	Feb.	June	Dec.
10	Aug. 1933	Dec.	Dec.	Dec.	Aug. 1933
11	Nov.	Aug. 1933	July	Jan.	July
12	June	Nov.	Nov.	Nov.	Jan.
13	July	Jan.	Jan.	July	Nov.

TABLE 85A.—RANK ORDER POSITIONS OF THE MONTHS BY SEPARATE AND COMPOSITE CRITERIA.

Month.	Character Figure.		CR.	C*r*.	Three Local Criteria Together.	All Four Criteria Together.
	Local.	International.				
1932 Aug.	3	$5\frac{1}{2}$	4	3	3	3
Sept.	$1\frac{1}{2}$	$2\frac{1}{2}$	1	1	1	1
Oct.	9	$2\frac{1}{2}$	6	5	$6\frac{1}{2}$	5
Nov.	12	11	12	12	12	13
Dec.	10	$5\frac{1}{2}$	10	10	10	9
1933 Jan.	13	$7\frac{1}{2}$	13	11	13	12
Feb.	4	$7\frac{1}{2}$	9	6	5	6
Mar.	7	4	3	4	4	4
Apr.	$1\frac{1}{2}$	1	2	2	2	2
May	5	9	8	7	$6\frac{1}{2}$	7
June	7	12	5	9	8	8
July	7	13	11	13	11	11
Aug.	11	10	7	8	9	10

and partly to use them for comparison with other measures of magnetic disturbance at Fort Rae, day-to-day algebraic changes in the mean values of H and Z have been tabulated in Tables 86 and 87. Monthly averages of these interdiurnal changes having no regard to sign are given in the bottom lines of the two tables. Such monthly averages for the horizontal component have been treated * as the bases of measures of magnetic activity and are denoted by U.

* *Terr. Mag.*, 37, 1 (1932).

At first it was intended that only U_H values for Fort Rae should be constructed, but if the outcome of an inquiry to be described in § 89 may be anticipated, the rank order of the 13 months on this basis differed so conspicuously from the order of the months when arranged by other local criteria that the U_Z values of Table 87 were also formed. In this table entries for 1932 August 1 and 1933 April 1–5 are lacking. The reason for the blanks in April have been already explained in § 25; August 1 is missing because of difficulties in determining a Z base line value for July 31 owing to adjustments to the standard variometer on that date.

TABLE 86.—INTERDIURNAL VARIABILITY OF H: ALL DAYS.

(Entries are differences between day $n-1$ and day n: unit $\frac{1}{10}\gamma$.)

Date.	1932.					1933.							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
1	+100	+68	+373	−136	−206	−238	+25	−169	+60	−641	+25	+273	+136
2	+838	+151	−2	+338	+150	+88	−229	−6	−50	+260	−16	−241	−155
3	−880	+130	+190	−73	+39	+94	+153	−21	−467	+110	+58	+356	+110
4	+231	+10	+97	+383	−74	−48	−42	+123	+585	−74	+234	−411	−5
5	−8	−223	+51	−303	+64	+75	+271	−98	−146	+136	+7	+354	−1106
6	+380	−317	+23	+193	−225	−479	−52	+26	−40	−199	+57	−214	+659
7	+18	+427	−6	−113	+358	+329	−81	+44	−82	+290	−136	−13	+232
8	−76	−87	0	+161	−101	−171	−46	+10	+25	−103	+159	+36	+165
9	−66	+144	−193	+93	−1147	+197	−26	+112	−269	+128	−280	−287	−175
10	+259	+215	−191	−71	+782	+126	+274	+21	−66	−29	+155	+304	+111
11	+44	+123	+452	−80	+244	−156	−153	−101	+389	−61	−109	−105	+17
12	+273	−73	−55	−500	−137	+177	−154	−365	+140	+299	+275	+207	+2
13	−292	−391	−189	+188	−338	+38	+68	+155	−143	−305	−142	−105	−221
14	−422	+328	+149	−361	−395	+8	−487	−33	−125	−68	−243	+63	−378
15	+157	−186	−1049	+533	−204	−526	−98	+22	+172	+172	+460	−76	+37
16	+390	+213	+427	−955	+560	+52	+539	+173	−246	+82	−197	+6	+467
17	−149	−46	−2	+812	−361	+26	+80	−241	−711	−64	−151	−33	−434
18	+38	−218	+596	+34	+481	+249	+24	−88	+1062	−433	+42	−151	+52
19	−87	−286	−475	−461	−127	−499	−576	+454	−462	+235	+25	+88	+238
20	−11	+8	−222	+495	+679	+288	+33	−815	−679	+152	+24	+21	−45
21	−131	+357	−427	+196	−239	+347	−116	−121	+755	+74	−271	+10	−591
22	+45	−55	+728	−72	−69	−168	+105	+309	−296	−182	+522	+115	+670
23	−435	−846	−283	−117	+19	−3	−10	−120	+144	+216	−102	−345	−442
24	+649	+657	+224	+248	+186	−214	−536	+137	+254	+8	+94	−320	−132
25	−304	−864	−622	−131	−211	+8	+596	−61	−53	+44	−115	+353	+348
26	+151	+1006	+1040	−92	+301	+192	+199	+336	+55	−107	+91	+151	+311
27	−559	−469	−424	+190	−121	+84	+122	−404	+287	+133	−613	+229	+6
28	−589	+369	+431	−365	+16	−73	+215	+461	+140	+352	+82	−487	+161
29	+148	+329	+88	+114	−118	−282	..	−339	−228	−611	+241	+362	−149
30	+27	−604	−471	+305	+120	+357	..	+236	+38	−58	+20	−123	+102
31	+471	..	−26	..	+86	+32	..	+291	..	−39	..	+136	−1
Mean U	265	307	307	270	263	181	190	190	272	183	165	193	247

Though the main inter-comparison with other criteria will still be deferred to § 89, it is of interest to compare the U_H and U_Z data among themselves. From Table 17, in which are shown average $a-q$ and $d-q$ excesses for H and Z, it might have been inferred that the U_H measures would be approximately double those of U_Z. Actually the averages of the 13 monthly U_H and U_Z values are $23{\cdot}3\ \gamma$ for H and $18{\cdot}1\ \gamma$ for Z. The values of U_H range from $16{\cdot}5\ \gamma$ (June) to $30{\cdot}7\ \gamma$ (September and October); U_Z from $10{\cdot}8\ \gamma$ (January) to $23{\cdot}2\ \gamma$ (April). In respect both of magnitude and range, U_H and U_Z as monthly indices of activity are comparable. But as these extreme values alone suggest, there is little agreement between them in arrangement of the several months in order of activity. For all 13 months the descending rank order is:

U_H Sept. Oct. Apr. Nov. Aug. (1932) Dec. Aug. (1933) July Mar. Feb. May Jan. June.
U_Z Apr. Dec. Oct. May Sept. June Aug. (1932) Aug. (1933) July Feb. Nov. Mar. Jan.

The only agreement between the two rank orders is that February is 10th on the list in both, and the next best agreement is that April and October occur in the top three months and January is either lowest or second lowest in both lists. But

TABLE 87.—INTERDIURNAL VARIABILITY OF Z: ALL DAYS.
(Entries are differences between day $n-1$ and day n: unit $\frac{1}{10}\gamma$.)

Date.	1932.					1933.							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
1	..	−190	− 166	+366	+ 252	+123	+ 92	+ 34	..	+1021	−405	−127	−135
2	−118	− 61	+ 303	−498	− 240	− 2	−231	− 74	..	− 703	+161	− 97	+ 71
3	+394	− 23	− 152	+ 28	+ 181	− 4	+179	+ 35	..	− 70	+ 30	+ 52	− 72
4	−362	+ 28	− 266	− 17	− 11	− 84	−128	− 76	..	+ 15	−346	−100	+ 66
5	+150	+ 65	+ 30	− 58	− 120	− 3	+ 12	+ 44	..	− 22	− 16	− 74	+791
6	−159	+696	− 18	+ 70	− 10	+366	− 41	− 71	+195	+ 38	+ 31	+255	−824
7	−143	−799	− 52	− 39	− 101	−467	− 5	− 8	+ 24	− 221	+113	−114	+227
8	+100	−443	+ 6	+ 53	− 172	+236	− 71	− 64	+ 4	− 47	−152	− 20	+ 26
9	+147	+156	+ 83	−112	+ 545	−217	−148	+ 37	+198	+ 4	−323	+432	−143
10	−387	+266	+ 3	+ 4	− 133	+ 80	+216	− 24	+ 20	+ 36	+419	−264	− 62
11	+ 41	−137	+ 73	+ 15	− 122	− 2	− 1	+ 19	−308	− 45	+ 45	+193	+ 29
12	−294	− 26	− 78	− 42	+ 26	− 19	− 4	+252	− 60	− 97	− 93	−317	+ 21
13	+243	+ 67	+ 46	+ 26	− 135	− 27	+ 23	−159	− 30	+ 52	−347	+ 97	+448
14	+307	− 5	+ 7	+329	+ 652	+ 52	+128	−113	+ 74	− 186	+233	− 46	+ 50
15	−143	− 22	+1028	−420	−1078	+246	−171	+ 93	−358	+ 305	−182	− 32	−285
16	− 67	+ 31	− 610	+313	+ 440	− 92	0	− 93	+421	+ 109	+276	+111	− 67
17	− 30	− 68	− 60	+233	+ 600	− 22	+ 12	+198	+308	− 243	+ 81	+248	+ 35
18	− 76	+284	− 200	−522	− 421	− 62	− 33	−296	−758	+ 230	+ 26	− 80	+ 89
19	+112	+170	− 96	+165	+ 170	+107	+392	− 21	+620	+ 185	−241	− 48	+ 76
20	+117	−112	+ 401	−254	− 209	− 30	−384	+ 83	+270	− 223	−187	−250	− 50
21	+170	−161	− 65	+ 59	+ 33	− 97	+460	+432	−627	− 290	+723	+210	+487
22	− 28	+201	− 187	− 35	− 115	−175	−542	−280	+463	+ 188	−345	+ 23	−603
23	−234	+572	+ 327	+145	+ 169	+ 62	+570	− 64	−461	− 20	− 59	+452	+366
24	−182	−154	− 281	−107	− 27	+ 31	−109	−133	− 7	− 125	− 33	−238	−157
25	−146	+ 9	+ 293	− 56	− 23	+152	+ 79	+153	+103	+ 178	− 48	+106	−108
26	− 28	−535	− 440	+ 12	− 200	− 69	−397	+101	+ 14	− 37	+ 37	−508	−100
27	+487	+252	+ 344	+ 8	− 19	−176	+ 9	+271	−163	− 29	+581	+359	− 66
28	+343	+ 91	− 352	+111	+ 286	+199	+ 93	−168	− 83	− 366	−265	−110	− 6
29	+286	−257	− 67	−209	− 76	+ 87	..	+ 49	+168	+ 534	+ 59	+ 44	− 10
30	−422	+200	+ 307	+ 68	− 210	− 24	..	−174	− 70	− 117	−299	+ 6	− 65
31	−195	..	− 40	..	− 52	+ 33	..	− 81	..	+ 639	..	−118	+108
Mean U	197	203	206	146	220	108	162	119	232	206	202	166	182

against these we have May 3rd lowest in U_H and 3rd (or 4th) highest in U_Z, and November 3rd lowest in U_Z and 4th highest in U_H. From what was said earlier in this section and elsewhere in the discussion it might have appeared that U_H and U_Z should be almost equally sensitive to disturbance effects, but the results just described make it clear that both cannot authoritatively represent the average state of affairs in the magnetic field at Fort Rae. Which of the two measures is in better agreement with other criteria of disturbance will be discussed in § 89.

§ 88. *Interdiurnal variability on* q′ *and* d′ *days.*—The contents of Tables 86 and 87 have been used to decide how far the individual daily entries are consistently of one sign in groups of days selected by other criteria. These groups are the 38 q' and 40 d' days already used in other connections. In regard to these days it should be stated that the mode of their selection was such as to weight unduly the mere oscillatoriness of the field during disturbance, and to discount the aspects of long period elevation or depression of the mean force for considerable fractions of a day or even whole days which are specially catered for by the U measures.

A summary of the analysis of the directions and magnitudes of H and Z change from the day before to each of the selected q' and d' days is given in Table 88. Extending for our present purpose the connotation of U as used by J. Bartels (monthly averages irrespective of sign) to cover the magnitudes of the individual changes from day $n-1$ to day n and denoting by $\overline{U}$ the mean U for groups of days, we see that over the group of q' days $\overline{U}_H$ is positive and $\overline{U}_Z$ negative. This is what we might have expected from the $a-q$ section of Table 17. But even among these selected q' days 14 (or 37%) in H and 15 in Z have U values of sign opposite to those of their respective $\overline{U}$.

TABLE 88.—MEAN INTERDIURNAL VARIABILITY OF H AND Z ON q' AND d' DAYS.

		Days of +ve Change.		Days of −ve Change.		Algebraic Mean of Both Groups.
		No.	Mean.	No.	Mean.	
			γ		γ	γ
38 q' days	H	24	15·7	14	7·0	+ 7·4
	Z	15	4·5	23	6·0	− 1·8
40 d' days	H	9	30·5	31	51·6	−33·1
	Z	27	41·1	13	32·1	+17·4

Within themselves the results from the group of 40 d' days are a little more consistent in having smaller proportions of U changes with sign opposite to those of the means for the whole group; nevertheless, they provide such a conspicuous anomaly as U_Z for December 15, when U_Z was not only negative but had the greatest numerical value of U_Z in the 13 months. It is the incidence of such anomalies which leads to U_Z from the 13 d' days of negative change being 32 γ compared with 41 γ from the 28 days of positive Z change.

If U measures for any one day were related, not to the mean value on the immediately preceding day, but to the mean for a month or longer period, there might be ground for suspecting that such anomalies were to be explained in terms of the use of false base line values arising from neglect of long-period temperature effects. But the use of daily mean values on consecutive days leaves little room for error of this kind. It must therefore be inferred either that the U measures of activity cannot be extended to cover regions of such highly localised disturbance as exemplified by Fort Rae, or that they take account of aspects of disturbance quite other than those on the basis of which the q' and d' days were selected. In view of the fruitfulness of the use of these q' and d' days for other inquiries already described, and in view of the lack of consistency between the U measures for the two major force components, it is probable that the earlier of those two alternative inferences is the better founded.

§ 89. *Comparison with interdiurnal variability measures of activity.*—Since the bases for the composite rank ordering of the months of the Polar Year discussed in the preceding section became available, J. Bartels has published * u and u_1 measures of activity for 1932 and 1933. It is of interest briefly to compare these measures with the local U figures given in Tables 86 and 87, and also with the other

* *Terr. Mag.*, 39, p. 1 (1934), and 40, p. 265 (1935).

measures discussed in § 86. This is done in Table 89. April, which is 3rd by U_H and 1st by U_Z as well as being easily 2nd by the composite criterion, is at the bottom of the list according to u. Further, no one of the first four months, according to the composite rank order from four criteria, occurs among the first four in the u list, and though, at the other end of the scale, there is partial agreement in that November and July appear among the last three places in both lists, January has 11th, 12th, and 13th places in the composite, U_H, and U_Z rank orders, but is 6th equal with March on the u standard. These anomalies suffice to emphasise further the inferences about the interdiurnal variability measures of activity drawn in § 88. In particular, the completely contradictory placing of April, even as between the u

TABLE 89.—RANK ORDER OF MONTHS ON INTERDIURNAL VARIABILITY AND COMPOSITE CRITERIA.

(Months arranged in order of decreasing activity.)

Order.	Rank Order according to			Composite Criterion.
	u.	U_H.	U_Z.	
1	May	Sept.	Apr.	Sept.
2	Oct.	Oct.	Dec.	Apr.
3	Aug. 1933	Apr.	Oct.	Aug. 1932
4	Dec.	Nov.	May	Mar.
5	Sept.	Aug. 1932	Sept.	Oct.
6	Jan.	Dec.	June	Feb.
7	Mar.	Aug. 1933	Aug. 1932	May
8	Aug. 1932	July	Aug. 1933	June
9	Feb.	Mar.	July	Dec.
10	June	Feb.	Feb.	Aug. 1933
11	Nov.	May	Nov.	July
12	July	Jan.	Mar.	Jan.
13	Apr.	June	Jan.	Nov.

and U measures, make it clear that the mechanism determining the changes in the daily mean value of the field components in low or moderate latitudes is not universally effective, and that therefore the u measures cannot be extended to include high latitude stations. It is also clear from the placing of such a month as May, which was characterised by large scale disturbance on only one or two days (1st and 2nd), that the u measures from moderate and low latitude stations are very largely influenced by such isolated occurrences.

§ 90. *Distinctive features of disturbance at Fort Rae.*—It is customary to supplement such a statistical survey of the magnetic field as has been given in earlier parts of this discussion by a description more or less detailed of the major features of the field behaviour on a selected number of days. This procedure will not be adopted here, primarily because it is at least questionable whether such verbal descriptions of the magnetograms are of real utility in reconstructing any particular disturbance, and also because photographic copies of all the magnetograms with complete details regarding scale and base line values can become available to anyone wishing them by application to the Bureau of the International Polar Year Commission, Copenhagen.

Here we shall give only brief notes on a few of the more characteristic types of short period disturbance (that is, of the typical perturbations lasting not more than a very few hours which constitute an average day's disturbance) together with a description of some less frequent but distinctive movements.

Owing largely to the great diversity of movement in disturbance at Fort Rae, both in regard to type and scale, classification is difficult. Of the various lines of approach which are open only two are practicable. We may start with a composite picture of a disturbed day derived from the average diurnal variations both of hourly mean values and of hourly ranges. This we may assume to represent the general trend of the disturbance field and its superposed irregular variations, and then we may consider in detail how the various features of such a picture are formed by reference to magnetograms for representative days. Or, starting from a survey of the details of a few magnetograms, we may select some apparently typical features and, on the basis of these, extend the examination to all the other records, retaining only those features which are found to be of frequent occurrence. A combination of these and other more empirical methods have in fact been used in the present survey, and as a result the magnetogram of 1932 September 24 (fig. 18) has been selected as illustrating

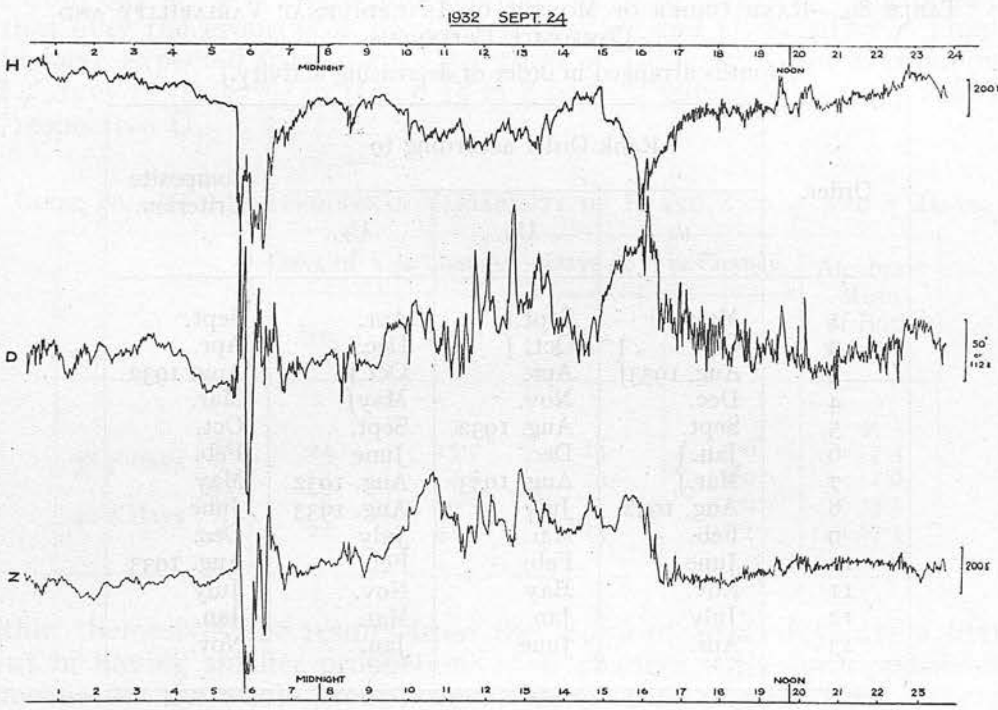


FIG. 18.—Reproduction of magnetic record for 1932 September 24 to illustrate characteristic types of perturbation.

some of the characteristics which will be described in subsequent paragraphs. To keep the details of the major perturbations on this day complete by avoiding reproduction of the multiple reflected traces, fig. 18 has been constructed as a composite magnetogram from the standard (la Cour) and auxiliary records. Increasing horizontal force, easterly declination, and vertical force are represented by movement up the sheet; the magnetic scales are indicated at the extreme right of the figure, and, on the G.M.T. scale used, local midnight is at 7h 44m.

At least three features of the disturbance illustrated in fig. 18 are typical:—

(i) The sudden and large oscillatory movements in all three components starting about 5h 45m and lasting for an hour;

(ii) The triangular bay-like perturbation in H and D centred at 16h simultaneous with a fall in Z from an irregular plateau of high values extending over several preceding hours;

(iii) The serrations which started in the second stage of this perturbation and continued throughout the remainder of the Greenwich day; and

(iv) The generally highly irregular field with no conspicuous conformity to type between the first and second forms of disturbance.

Since the three types of perturbation just indicated will frequently be referred to in subsequent paragraphs, they will be referred to as N, M, and O where the N alludes to the night-time occurrences of the large sharp oscillations, M refers to the irregular bays which occur in the morning and forenoon hours, and O the oscillations beginning in the morning and continuing into the evening hours. Fig. 19 illustrates N and M movements—the latter double—on two consecutive days at another time of year. In this figure the two H and the two Z records have been arranged below each other, with the time scales displaced by two hours in illustration of another phenomenon to be discussed later (§ 96).

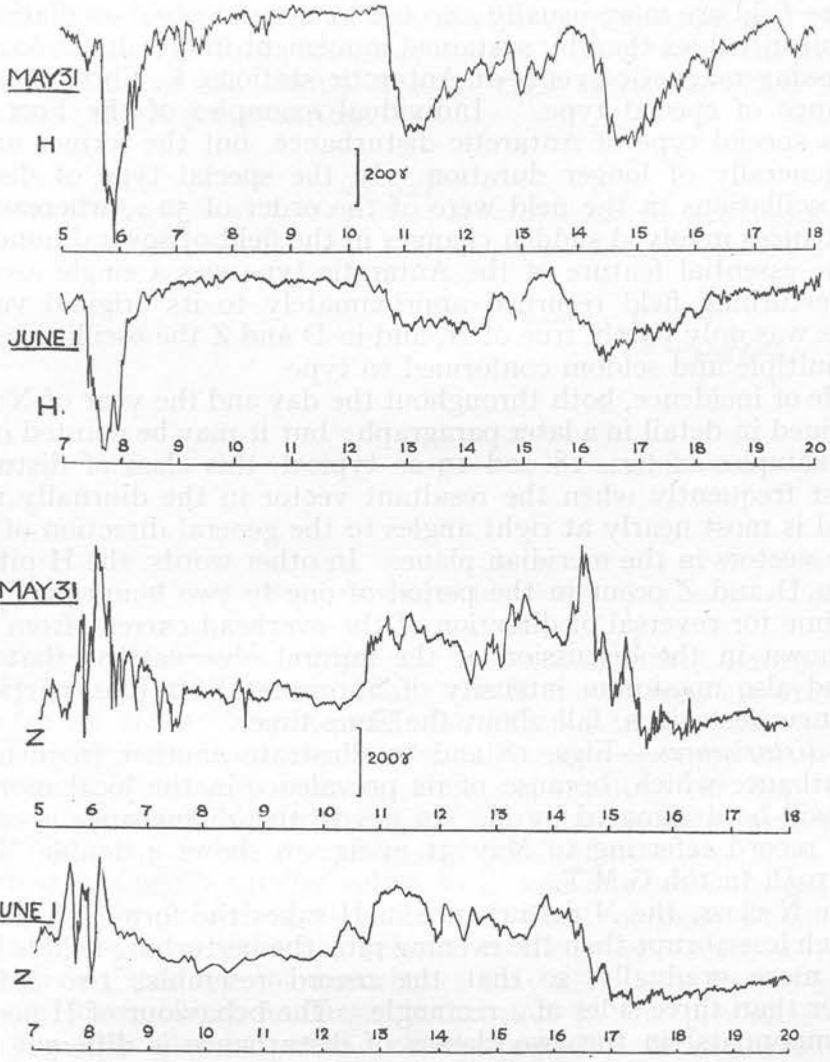


FIG. 19.—Parts of magnetogram for May 31 and June 1 illustrating N perturbations and repetition of similar movements on consecutive days.

§ 91. N *disturbances.*—As exemplified in figs. 18 and 19, the dominant features of this class of disturbance are the sharp depression in H occurring within a very few hours of midnight (and more frequently before than after midnight) following on a period of comparative quiet in the evening. The initial H depression is usually introduced by a sudden fall of 200 γ or more in a few minutes, after which the field remains depressed for periods of one-half to two or three hours, but with occasional large oscillations some of which may further step down the field momentarily by another few hundred gammas. The recovery to normal is almost invariably slower and less regular than the initial fall. Simultaneously with these changes in the horizontal field, D and Z are also very highly disturbed, but not so systematically as in H. In the example of fig. 18 the initial movement in H exceeded 600 γ, while Z rose by 280 γ, fell in a few minutes through 800 γ, and then rose irregularly in sudden large oscillations. Easterly D in the same disturbance was first increased by about 2°, swung west through nearly 4° after a second eastward excursion, and then towards the end of the movement was very oscillatory slightly above its mean value before becoming steady again.

In so far as these N disturbances seldom show any roundness or approximate symmetry of form they cannot be described as bays. In the usual bay movement all three elements undergo comparatively simple and similar changes. But during the time when H is so strongly depressed at Fort Rae, the east and vertical components of the field are more usually affected by several rapid oscillations above and below their mean values than by sustained movement in one direction.

In discussing magnetic events at Antarctic stations, C. Chree described a class of "disturbance of special type." Individual examples of the Fort Rae N class resemble this special type of Antarctic disturbance, but the former are both much larger and generally of longer duration. In the special type of disturbance the constituent oscillations in the field were of the order of 50 γ, whereas at Fort Rae the N disturbances involved sudden changes in the field of several hundred gammas. Moreover, the essential feature of the Antarctic type was a single oscillation, after which the perturbing field returned approximately to its original value. But at Fort Rae this was only partly true of H, and in D and Z the oscillations were almost invariably multiple and seldom conformed to type.

The mode of incidence, both throughout the day and the year of N disturbances, will be examined in detail in a later paragraph; but it may be pointed out here that, taking the examples of figs. 18 and 19 as typical, this class of disturbance tends to occur most frequently when the resultant vector in the diurnally recurring disturbance field is most nearly at right angles to the general direction of the majority of the hourly vectors in the meridian plane. In other words, the H pits and violent oscillations in D and Z occur in the period of one to two hours just preceding the most usual time for reversal of direction of the overhead current from WE. to EW. It will be shown in the discussion of the auroral observations that the greatest frequency and also maximum intensity of aurora at Fort Rae, particularly in its more active manifestations, fall about the same time.

§ 92. M *disturbances*.—Figs. 18 and 19 illustrate another frequently recurring type of disturbance which, because of its prevalence in the local morning or forenoon hours, will be designated by M. In fig. 18 this disturbance is centred at 16h G.M.T.: the record referring to May 31 in fig. 19 shows a double M disturbance lasting from 10½h to 16h G.M.T.

As in the N class, the M disturbance in H takes the form of a depression, but is usually much less abrupt than the evening pit; the perturbing field is both imposed and relaxed more gradually, so that the record resembles two sides of a 60° triangle rather than three sides of a rectangle. The behaviour of H (as, in fact, also the other components) in the two classes of disturbance is different also in that, whereas the major movements in the N class of disturbance are generally free from serrations, those of the M class are highly irregular, with frequent small rapid perturbations, as if due to an additional disturbance field which is mainly absent in the night-time. Occasionally, as in the example of September 24, the disturbance in D is of a similar form to that in H, except that easterly declination is increased as the horizontal field is diminished, but the behaviour of Z is different. The perturbation accompanying the H pit in the late evening usually leaves Z well above its mean value. During the subsequent early morning hours this element remains high as an irregular plateau till, at the time of the M depression in H, Z falls to a more normal level.

As is also true of the more abrupt N disturbances, the generally slower, but on occasion not less intense, M disturbances may be multiple. They may occur as early as 9h G.M.T. (1h Z.M.T.) and as late as 16h or 17h; their most frequent time of maximum phase is about 14h G.M.T. (6h Z.M.T.), when the overhead current system producing the regular disturbance variation is a maximum in the EW.

direction. If the M movements occur early, they frequently share some of the suddenness of N, especially in the middle of the movement, near the time of greatest H depression.

Before describing two further disturbance types it is worth recalling that the curves in fig. 15, showing the diurnal variation of short period irregular disturbance, indicated two intervals each day when such disturbance was most common. In addition to the pre-eminent maximum of D_i falling on the average slightly before midnight, each curve of fig. 15 showed a recrudescence in the local morning (5–7h). This includes the time just quoted for the M class of perturbations. Hence, if we identify the main midnight and secondary maxima in D_i with the two classes N and M, it may be deduced that on the average these latter are either less frequent or less intense than the N perturbations.

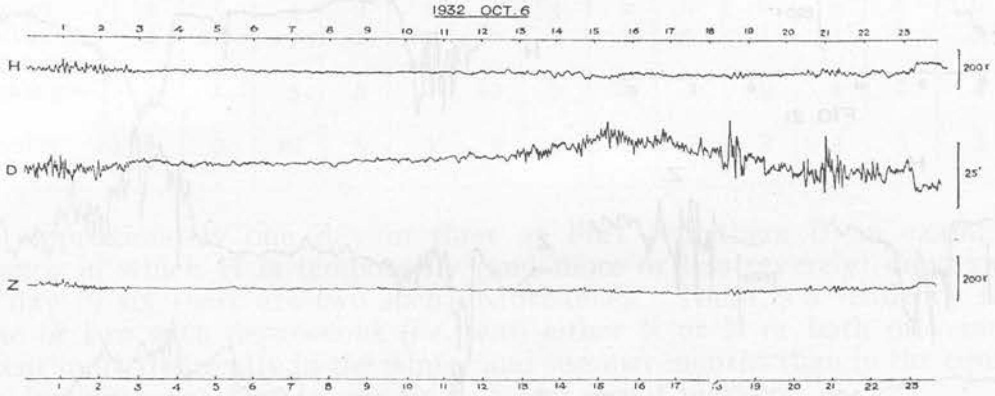


FIG. 20.—Magnetogram for 1932 October 6, showing oscillatoriness in daylight hours on a quiet day.

§ 93. *Oscillatory disturbance.*—Figs. 18 and 20 illustrate another prominent feature of disturbance at Fort Rae. While the M movements are still in progress it is common for all three components to be affected by irregular but persistent oscillations. This type of disturbance is usually most strongly developed in the forenoon, afternoon, and early evening hours, continuing till near the time of incidence of the N class of disturbance. It is therefore very largely a daylight phenomenon. The amplitudes of constituent oscillations range from 5 γ to over 50 γ in H, with only slightly smaller values in Z, and increase with the intensity of the disturbance in the preceding night hours. Their periods, which range from 1 to 10 or 12 minutes, have little clear relation to the general state of the field.

As fig. 20 shows, this type of disturbance may also occur in the light hours of days which have been free from large disturbance in the preceding dark hours. On such days (*e.g.* 1932 October 12 and 18) the period of the oscillations may be as great as ten minutes and have an amplitude of 10–20 γ, whereas on the afternoon of a disturbed day (*e.g.* 1932 August 29, 20–21h G.M.T.) the amplitude may be 50 γ, but with the period reduced to about three minutes.

Not infrequently the successions of oscillations forming this type of disturbance group themselves in series of increasing and decreasing amplitude such as might be produced by superposing sets of elementary oscillations having slightly dissimilar periods.

§ 94. *Recovery movements.*—A further type of disturbance is illustrated in fig. 21. This is less frequent than the types described in preceding paragraphs, but none the less characteristic. In this type, which, if present, is always most noticeable in H, but typical also of Z, the record suggests a sudden imposition of an additional field (almost invariably effecting a decrease in H), followed by a relaxation which at first is also quick but becomes slower as the additional field disappears and the normal field value is recovered. The form of the effect, in H at least, is very similar to the building-up of the earth's surface electric field after sudden destruction by a lightning discharge. This discharge-and-recovery type of movement is confined to the late evening and early morning hours—to the period, indeed, when aurora is most frequently observed at Fort Rae. Occasionally (as in fig. 21) the movement is repeated three or four times in quick succession.

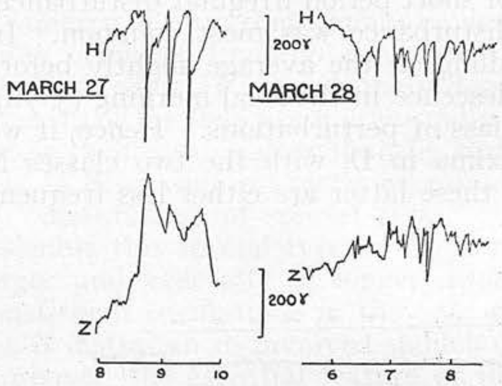


FIG. 21

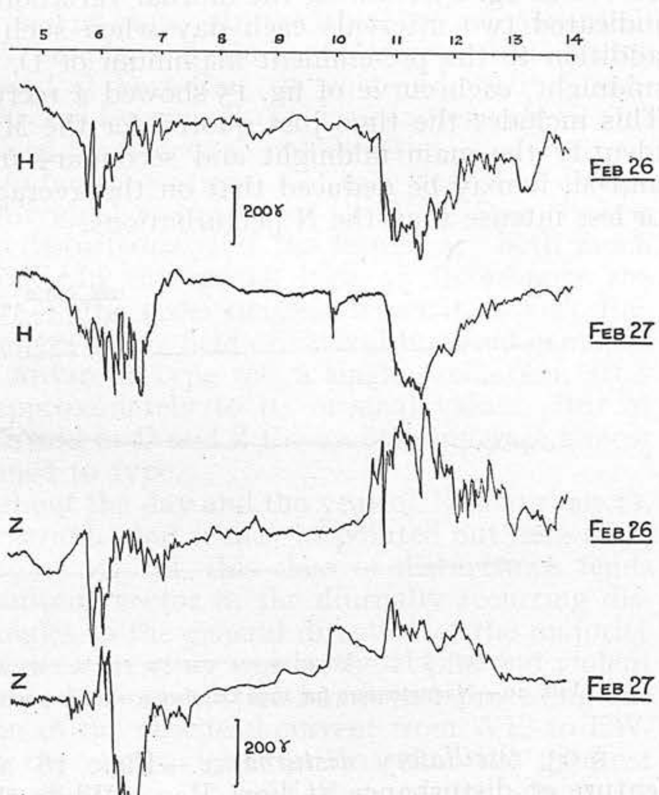


FIG. 22

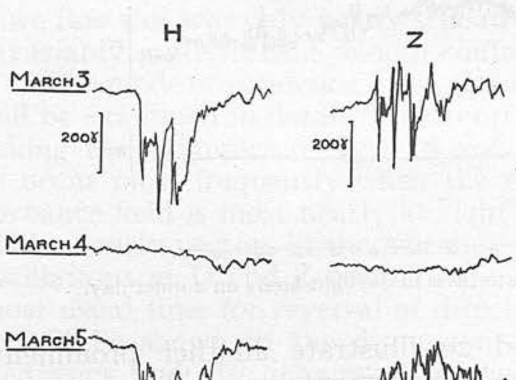


FIG. 23

FIG. 21.—"Discharge and recovery" movements.
FIG. 22.—Magnetograms illustrating repetition of double movement on two consecutive days.
FIG. 23.—Illustration of repetition of perturbation with skip of one day.

§ 95. *Seasonal and diurnal distribution of* N *and* M *movements*.—With a view to examining the behaviour of the magnetic field at Lerwick coincident with various classes of disturbance at Fort Rae, all the Fort Rae records had been examined and each day allocated to one of five classes very roughly descriptive of the behaviour of H. This was done before the present examination of disturbance characteristics was begun, and therefore before the differences between the two classes of N and M movements were appreciated. In this somewhat perfunctory survey the five classes of days used were those in which occurred :—

(1) A large single depressional perturbation in H;
(2) Two such perturbations;
(3) More than two;
(4) Continuous irregularity, mainly on a large scale; and
(5) Only small movements, otherwise quiet.

When a day had at most two isolated and fairly simple disturbances, either N or M, the approximate hour of culmination of the disturbance was noted: if H was highly oscillatory during the depression, the hour of the disturbance was taken to be that one most nearly half-way between the beginning and end of the movement. Table 90 summarises the distribution of occurrences of days in each of the five classes, and Table 91 shows how the times of the movements on days of single and double disturbance were distributed throughout the day.

TABLE 90.—MONTHLY FREQUENCY OF DAYS WITH LARGE H MOVEMENTS OR OTHER DOMINANT FEATURES.

	1932.					1933.								Total.
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	
Single bays	9	7	5	16	16	7	6	8	5	11	10	9	11	120
Double bays	7	5	4	2	3	5	3	2	6	6	5	9	6	63
Multiple bays	4	10	7	1	3	0	5	5	5	2	7	6	5	60
Frequent irregular large movements	3	1	5	5	6	10	7	10	8	9	4	2	4	74
Mainly quiet	8	7	10	6	3	9	7	6	3	3	4	5	5	76

On approximately one day in three at Fort Rae there is an example of a disturbance in which H is temporarily (and more or less severely) depressed, and on one day in six there are two such disturbances. There is a tendency for days with one or two such depressions (*i.e.* with either N or M or both movements) in H to occur more frequently in the winter and summer months than in the equinoctial months, but any such bias to one time of year is not marked.

TABLE 91.—DIURNAL FREQUENCY DISTRIBUTION OF H PERTURBATIONS.
(a " · " signifies a ½ value.)

Nearest G.M.T. Hour.	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total.
A.—From days of single and double movements together.																	
Year (13 months)	·	1	7	13	31	30	23·	25·	18·	13	17	32·	17	10	3·	2·	246
Winter (4 ,,)			·	3	5·	8	9	6·	7	5·	7·	9·	4	2	1	1·	71
Equinox (4 ,,)	·	·	4	2·	4·	9	6	5·	4·	2	5	6·	4·	4			59
Summer (5 ,,)		·	2·	7·	21	13	8·	13·	7	5·	4·	16·	8·	4	2·	1	116
B.—From days of double movements alone.																	
Year (13 months)		·	4	11·	18·	14·	11·	7·	5	5·	9	19·	9·	5·	2	2	126
Winter (4 ,,)			·	3	2	4·	3·	·	·	2	2·	3	2	·	·	1	26
Equinox (4 ,,)			1	2·	4	5	3	1·	2	1	3·	5	2·	3			34
Summer (5 ,,)		·	2·	6	12·	5	5	5·	2·	2·	3	11·	5	2	1·	1	66
C.—From days of single movements.																	
Year (13 months)	·	·	3	1·	12·	16	12	18	13·	7·	8	13	7·	4·	1·	·	120
Winter (4 ,,)					3·	4	5·	6	6·	3·	5	6·	2	1·	·	·	45
Equinox (4 ,,)	·	·	3		·	4	3	4	2·	1	1·	1·	2	1			25
Summer (5 ,,)				1·	8·	8	3·	8	4·	3	1·	5	3·	2	1		50

Table 91, A, confirms that there are indeed two times each day when H movements are most likely to occur, viz. at 7h and 14h G.M.T., the frequency of occurrence of the N and M types being approximately equal. The separate seasonal distribution in the same section of Table 91, A, also suggests that while the M disturbances show no seasonal variation in their usual hours of incidence, the N disturbances are more likely to occur two hours earlier in the summer months and one hour earlier in the equinoctial months than in winter. This same tendency holds for days of single and double disturbances separately (Tables 91, B, C).

§ 96. *Repetition of isolated perturbations.*—In view of the comparative frequency of large scale and yet isolated movements, especially those of N class, and their concentration into a limited number of the evening hours, it is to be expected that recurrence of similar movements about the same time on successive days will not be uncommon. From the foregoing analysis it may be assumed that such a tendency to repetition is a characteristic feature of disturbance at Fort Rae. But even within the N and M types there is wide scope for variety of form and time of incidence. The examination of these movements has therefore been taken further with the intention of detecting any tendency to real repetition in the sense of persistence of detailed form from one day to the next, and to determine whether, if such persistence occurred, there was any indication of a systematic lag or advance of the times of incidence of such movements on consecutive days.

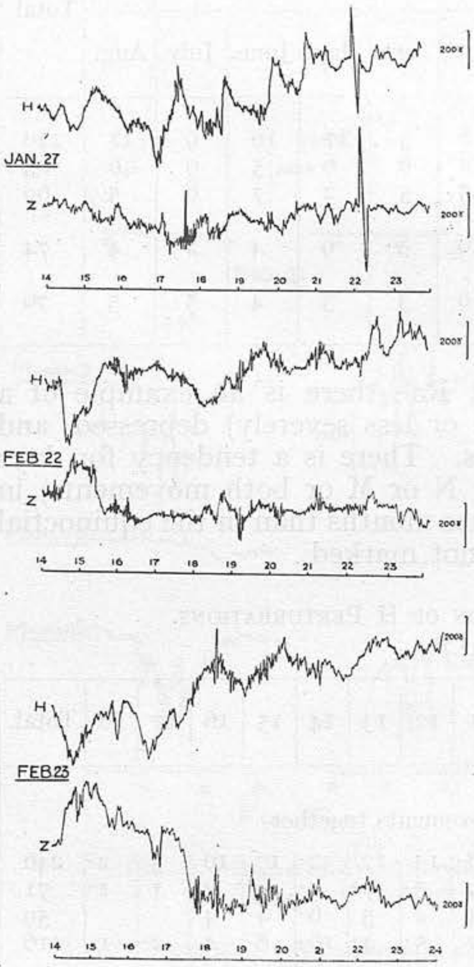


FIG. 24.—Repetition of disturbance type after 27 days.

This has been done by superposing, over a table with a glass cover illuminated from below, consecutive pairs of magnetograms, and noting all occasions when perturbations of a few hours' duration showed distinct evidence of resemblance in either the H or Z components or both. As will presently be described, the examination was extended to a comparison of each day n with day $n+2$ and to a less extent with days $n+26$ to $n+28$. In view of the results given in Tables 90 and 91 the comparison was limited to the five periods each of three hours beginning 3h G.M.T. (19h Z.M.T.), against each of which a roughly estimated duration of lag or advance was entered (for H and Z separately).

The detailed results of this inquiry are not reproduced, but the net conclusions are summarised as follows:—

(i) There are unquestionable examples of persistence of distinctive features from one day to the next, but the chances of an advance in the recurrence are almost as great as for a lag. The H and Z curves in fig. 19 for parts of May 31 and June 1 illustrate how close the resemblance on two consecutive days may be, though with the repetition on the second day delayed by about two hours. Fig. 22 is another example of considerable repetition of detail with lag from the first to the second day.

(ii) Occasionally a characteristic disturbance may persist over three or four days, the disturbance on each successive day of the series appearing progressively earlier or later. For example, an N movement on 1932 September 18 reappeared progressively earlier on the 19th, 20th, and 21st, so that by this last date it was three hours earlier than on the 18th.

(iii) It is not uncommon for a day to be skipped in a recurrence—that is, a disturbance on day n may reappear with a considerable degree of similarity in time and form on day $n+2$ but with no counterpart on day $n+1$. On such occasions the repetition is almost as equally likely to be in advance of, as lagging behind, its predecessor. Fig. 23, showing parts of the H and Z magnetograms for March 3, 4, and 5, illustrates this phenomenon.

(iv) Examples (necessarily limited) of recurrence of disturbance type, after an interval of 25 to 30 days, included the repetition on 1933 February 21, 22, and 23 of a series of large waves in H in the period 18–24h (see fig. 24), which had also been a feature of the disturbance on January 26, 27, and 28. The reappearance on 1933 June 13 of a double N movement unusually early in the evening, followed by a subsequent movement of similar N type at midnight, both of which had been prominent on May 18, is another illustration of this mode of 27-day recurrence of detail (*cf.* § 76).

(v) Disturbance in one element, *e.g.* H, occasionally retains similar characteristics for two or more consecutive days, while disturbance in the other element completely alters its form.

(vi) 1932 September 27–28 is an example of a repetition with a lag of $1\frac{1}{2}$ hours in H but only about 40 minutes in Z, and the records of November 4–5 illustrate a reversal of direction of change of H force with a lag of $1\frac{1}{2}$ hours.

(vii) On some days of vague repetition of disturbance type it would seem that the central part of the repetition is comparatively undisplaced, while the earlier and later stages are respectively delayed and advanced. The result is that the repetition on the second day is a compressed counterpart of the disturbance on the first day; this compression may be accompanied by a large reduction in force scale.

NON-INSTRUMENTAL AURORAL OBSERVATIONS

§ 97. *The scope of the observations.*—In addition to the programme of double station auroral photography for determination of position, a detailed log of all auroral activity was maintained throughout the period of occupation of the main base station. Except on a few questionable occasions, when a spectroscope was used for verification of the presence of weak aurora, the extensive notes forming the record of these observations are based solely on the evidence of the eye. Aurora was sufficiently strong to be detected on 273 nights, and details of duration and behaviour are available for 270 of these; the description of its behaviour for these 270 nights covers a total of 1458 hours or an average of 5·4 hours per night.

In the early part of the auroral season (1932 August and September) the method of observation adopted was for an observer to be more or less continuously out-of-doors communicating his observations, with the greatest possible detail, by telephone to an assistant acting as a recorder equipped with a chronometer in a nearby hut. As the season advanced it became clear that the continuance of this procedure throughout the year was impracticable. It would have entailed observations for continuous periods of 15 hours around mid-winter when the general demands of the other aspects of the station's work and the double station auroral photography were themselves requiring all the time of the five observing members of the party. After September 20 the routine of visual auroral observations was therefore somewhat curtailed in the following way:—

(*a*) Throughout the period of darkness, and extending at both ends of the night into strong twilight, observations were made at each exact quarter-hour G.M.T. by shifts of single observers.

(*b*) As soon as the presence of aurora was detected, observations were made at each exact five minutes, except during periods of weak quiet displays when little change in intensity and form was in progress. Then observations were made twice each quarter-hour.

(*c*) During periods of active change and movement, observations were made as continuously and frequently as possible—as frequently, indeed, as the observer could take stock of the activity, note what he had seen, and begin observing again.

In this way single observers could carry on non-photographic observations for periods of four or five hours.

Another modification was gradually introduced. In the earlier months not only were the observations continuous, with the times noted to the nearest five (often single) seconds, but the position of the auroral forms were described as exactly as possible by reference to their stellar background. During periods of moderately quiet display with only a few arcs and ray pencils or bands in the sky this was possible, though even then longer time was found to be required for noting the details than nature usually allowed before fresh movements began. In moderately active periods at a station so near the zone of maximum activity as Fort Rae the speeds of the observer and recorder are taxed to the utmost: when the display becomes really active detailed description is simply impracticable. The whole sky may be filled with rayed arcs, curtains, and draperies forming and dissipating every few moments; complete changes in position, intensity, colour, and form are continuously in rapid progress.

Now the uses of detailed description of aurora are threefold:—

(i) To gain a knowledge of the general characteristics of aurora as locally observed;

(ii) To allow reconstruction of the position of various forms for linking-up with similar observations at neighbouring stations; and

(iii) To provide a basis of auroral material for correlating with concomitant changes in the magnetic field.

At Fort Rae our nearest auroral observing neighbours were the stations at Coppermine, Sitka, and Chesterfield, of which the nearest, Coppermine, was over 300 miles distant. Hence the likelihood of our observations being adapted to reconstruct situations over such an extensive field was negligible.

For correlation with the synchronous magnetic changes the essential desiderata are:—

(*a*) A description of the major auroral forms present at as frequent intervals as possible;

(*b*) Notes of the intensity, area of sky covered, colouring, and vivacity of those forms; and

(*c*) A statement, not necessarily detailed, of the position of the forms with respect to the magnetic prime vertical (*i.e.* the vertical plane through the station perpendicular to the local magnetic meridian) and their approximate elevation above the horizon.

These same details will supply all that is necessary for the examination of general characteristics.

Therefore, after September 1932, when the attempts to maintain strict continuity in observation were abandoned, the positional details were frequently reduced to the constellations and major stars for regional definition of the more important auroral forms, and for the weak and diffusely structured types only the quadrant of the sky (N. S. E. or W.), rough elevation (high, middle, or low sky), and whether along, parallel with, or athwart the magnetic prime vertical. In this way more frequent observations within a short period of intense activity could be made while preserving sufficient detail for all possible uses of the notes.

§ 98. *Estimation of auroral intensity.*—A scale of intensity 0 to 4 was used as advocated in the *Photographic Atlas of Auroral Forms* (Supplement I, p. 12), but not simply and rigorously. Since, on such a scale, 0 indicates "no aurora perceptible," only four figures are available for characterising the entire gamut of auroral intensity. From an early date at Fort Rae we found it almost indispensable to introduce subsidiary graduations into the primary scale. On our modified scale, 0 still indicated "no aurora perceptible," but instead of jumping to 1 for "faint aurora," 0+ on our scale meant "just perceptible aurora"; 1- was still "very feeble aurora" but appreciably brighter than 0+; 1 indicated simply "feeble or faint aurora," with 1+ a little better than this. Continuing in this way with the + and - suffixes to each of the scale members, 2- meant aurora of not quite moderate intensity but nearer this than the "just-better-than-feeble" 1+; 2 was simply moderate intensity, with 2+ somewhat better and qualifying for being described as "bright", and so on.

It is not claimed that the signs affixed to the scale numbers have an invariable significance. But by allowing more scope in assigning intensities we believe it probable that the use of such qualifying signs tends to ensure a more precise interpretation and significance for the primary numbers of the intensity scale. Moreover, their use introduced no radical departure from international practice; the signs can be reincorporated into the primary scale numbers when required for comparison with other stations. For rigorous statistical work the + or − sign would have a value of one-third of the unit intensity on the 0 to 4 scale.

For any one observer to maintain a continuity of standard in estimating by eye alone a phenomenon which in its frequency, violence of activity, and wideness of distribution is new to him is practically impossible. It is equally impracticable without artificial means to ensure a uniformity of standard between several observers. In future work of this type a useful aid would be a small pocket-size box in the lid of which might be four small windows tinted with varying degrees of intensity of the dominant yellowish-green colour of the aurora and illuminated from below by a modified pocket torch. With the intensities standardised at a central institution and the illumination maintained steady, a uniformity not only at one station but among all co-operating stations could readily be secured to the degree of accuracy required in such work.

At Fort Rae not only were the above-mentioned variations from uniformity present (though perhaps not to any serious extent), but it is likely that the whole range of intensities were also scaled down compared with those of stations whose observers adhered to the instructions in the Supplement to the *Auroral Atlas*. At Fort Rae intensity 4 was reserved for the very strongest outbursts of activity; 3+ would probably be our equivalent of the "very bright" (4) of the instructions. In addition, since on our modified scale two intensities 0+ and 1− were available before we required to use the lowest international figure 1 to indicate the presence of aurora, there was a tendency to comprise the 1 to 4 of the international range into 0+ to 3 or 3+ of the Fort Rae scale. Certainly the "intensity" of the Milky Way would have been estimated as 0+ or at most 1− on most nights at Fort Rae, and, correspondingly, a "cirrus band in moonshine" would have merited only a 1+, whereas the international instructions would give the Milky Way 1 and the cirrus band 2.*

§ 99. *Auroral "activity" figures.*—Before leaving this aspect of visual auroral observing, a more serious defect in present-day practice deserves attention. The scale of intensity refers only to the mere brightness of aurora present at any moment; it gives no scope for indicating the general activity of the phenomenon. On many occasions an area of a few square degrees of quiescent aurora (*e.g.* a partial rayband or tuft) lying low on the horizon may, by its mere brightness, merit a 3 or even 3+, while at another moment the greater part of the entire sky may be filled with draperies in violent movement and be highly coloured in dull red, crimson, or purple (all colours less bright to the eye than the usual yellow-green of the normal form) and yet only warrant the intensity figure 1 when judged on the merits of its mere visual brightness.

Though it is obvious that the estimation of the activity of aurora (in the sense of movement) combined with amount (in the sense of area of sky covered) is difficult to compound with brightness, until some composite "activity" scale is introduced the figures of auroral intensity as presently used can give only an inadequate representation of the auroral state of the sky. This is specially important when using the auroral data for correlating with synchronous perturbations in the earth's magnetic field and with surface earth currents.

§ 100. *The auroral log.*—The detailed descriptive notes of visual observations covering the 1458 hours of display at Fort Rae during the Polar Year are too extensive

* *Photographic Atlas of Auroral Forms*, Supplement I, p. 13.

for reproduction. They are in manuscript in four foolscap size volumes and one quarto size, and may be consulted on application to the Royal Society, London. So far the notes have been partially utilised in several ways of which an account will now be given.

§ 101. *Seasonal distribution of auroral frequency.*—The Greenwich day began approximately $7\frac{3}{4}$ hours before the local day. Hence on all but mid-winter days the dark hours of any one night at Fort Rae were conveniently comprised in one Greenwich day. Table 92 shows the number of quarter-hours on each such day

TABLE 92.—DURATION (IN $\frac{1}{4}$-HOURS) OF AURORA OBSERVED ON EACH GREENWICH DAY.

Day.	1932.					1933.						
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	July.	Aug.
1	..	7	16	*c*	49	53	40	*c*	31	17	..	1
2	*c*	*c*	*a*	23	55	52	44	20	1	17	..	..
3	*c*	1	32	*c*	17	60	13	10	31	5	..	9
4	*c*	12	14	12	49	22	13	20	23	15	..	2
5	7	19	4	*c*	43	22	39	24	*c*	*c*	..	16
6	1	26	1	*c*	36	50	13	22	12	*c*	..	2
7	6	25	26	*c*	37	46	29	5	17	*c*	..	9
8	13	27	33	4	24	35	30	16	*c*	3	..	*c*
9	14	27	24	*c*	9	23	*c*	18	16	7	..	2
10	9	22	19	*c*	16	3	15	3	16	8	..	3
11	4	1	14	10	9	19	*c*	*c*	22	6	..	12
12	2	*c*	2	*c*	2	4	*c*	22	23	4	..	2
13	10	25	*c*	29	27	*c*	*c*	26	21	*c*	..	11
14	15	*c*	*c*	2	44	*c*	32	28	11	*c*	..	16
15	*c*	19	26	7	30	45	37	28	24	*c*	..	*c*
16	13	2	1	43	13	22	22	29	19	..	..	14
17	8	22	*c*	20	50	41	16	25	21	5	..	4
18	14	21	*c*	33	48	1	28	37	23	..	..	17
19	17	22	30	*c*	*c*	52	51	38	21	1	..	*a*
20	21	23	26	39	1	52	44	2	20	..	..	*c*
21	18	13	13	42	*c*	6	48	13	23	..	..	*a*
22	12	28	13	6	3	43	40	32	24	1	..	14
23	22	15	12	49	*c*	57	44	29	*c*	..	..	5
24	19	20	29	6	21	59	44	32	13	..	4	10
25	23	21	6	26	21	52	38	36	12	..	..	19
26	20	29	24	34	62	56	36	20	*c*	..	..	23
27	23	31	3	32	21	49	46	7	*c*	..	..	23
28	19	34	*c*	47	37	25	*c*	26	5	..	4	5
29	*c*	23	*c*	4	44	6	..	15	8	..	..	20
30	22	35	*c*	35	54	21	..	21	9	..	2	22
31	*c*	..	1	..	26	34	..	34	..	..	4	10
Total No. of $\frac{1}{4}$-hours.	332	550	369	503	848	1010	762	638	446	89	14	271
No. of days.	24	27	24 (23)	21	28	29	23	29	25	12	4	27 (25)
Av. No. of $\frac{1}{4}$-hours per day.	14	20	15	24	30	35	33	22	18	7	3	10

of the 13 months, August 1932–August 1933, during which aurora was observed or its presence noted if strong enough to be seen through cloud. An entry of *c* in the table is to be interpreted as meaning that no aurora was observed, but that the sky was heavily and uniformly clouded during the dark hours ("impossible" nights); an entry *a* against 1932 October 2 and 1933 August 19 and 21 means that aurora was observed spasmodically behind cloud but no duration noted. June 1933 was the only month in which no aurora was observed. In May it was seen as late as the 22nd, when the sun was above the horizon for over 18 hours and twilight was strong throughout the remainder of the night, and again on 1933 July 24 when similar conditions obtained. Fig. 25 shows the distribution of those quarter-hours of aurora on each Greenwich day.

According to Table 92, January 1933 was the month of most prevalent aurora, with December 1932 and February 1933 the months of next greatest number of hours of observed activity. If the quarter-hour before Greenwich midnight on December 26 is included in that day, aurora was continuously present for 15½ hours. During December and January aurora was observed on 25 nights for upwards of 10 hours each night, and as early as 1932 August 20 for over 5 hours.

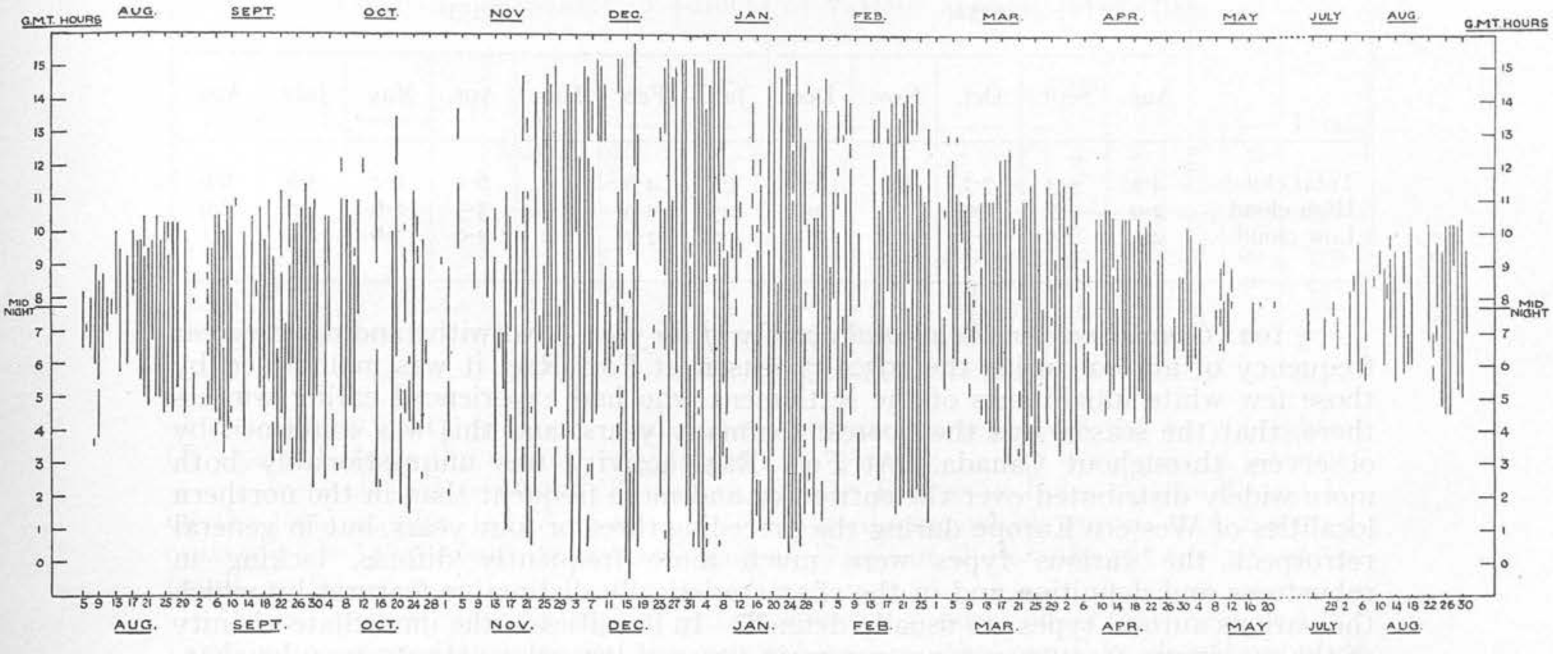


FIG. 25.—Duration of aurora on each Greenwich day.

In considering the reality of an annual variation in auroral frequency the two very important factors of varying duration of darkness and cloudiness play an important part. If the nights of all months from August to May had been equally cloudy it is very probable that the frequency of aurora (reckoned as the number of quarter-hours each night when aurora of any intensity was observed) would have been directly proportional to the duration of darkness. Certainly in August and May, which may be taken as the first and last months respectively of the auroral season at Fort Rae, aurora was observed in the evening as soon as conditions of twilight permitted, and continued till morning twilight again became too strong. The same was true of the mid-winter months.

As it is, the last line of Table 92, giving the average number of quarter-hours of aurora per night, shows that the frequency of appearance fell steadily from January to May, and only October and November 1932 have values below what might have been expected from a strictly direct proportion between the frequency of aurora and length of night. The anomalies of October and November are to be explained in large measure by an increased incidence of cloud in those months. Table 93 gives the average monthly amounts (in tenths of the sky covered) of cloud at the three observational hours nearest midnight, viz. 20h, 23h, and 2h zonal mean time corresponding with 4h, 7h, and 10h G.M.T. If we accept, as the best measure of conditions adverse to auroral observations, the average amounts of low cloud, line 3 of Table 93 makes it clear that such conditions were much more frequent in October and November than in all the other auroral months.

One further inference may be made from the data of Table 92. Excluding the period of one week in the middle of May and another period at the end of July and early days of August when aurora was indeed observed, but when twilight was too strong throughout the night for all but the brightest forms to be seen, aurora was observed on 100% of all possible nights. From this and other facts about the distribution of aurora in the sky, which will be described later, it may be inferred that Fort Rae is very near, if not actually under, the zone of maximum auroral frequency.

TABLE 93.—MEAN CLOUD AMOUNTS DURING NIGHT HOURS.
(Unit: tenths of sky covered.)

	1932.					1933.						
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	July.	Aug.
Total cloud .	4·1	5·3	7·7	6·2	6·0	4·4	4·6	5·4	6·2	6·2	5·8	6·0
High cloud .	2·0	2·7	1·0	1·6	2·5	1·3	2·9	3·3	3·3	2·6	2·9	2·9
Low cloud .	2·1	2·5	6·7	4·6	3·5	3·0	1·7	2·2	2·9	3·6	2·9	3·1

§ 102. *General note on the auroral activity of the year.*—Notwithstanding the great frequency of aurora during the 1932–33 season at Fort Rae, it was maintained by those few white inhabitants of the settlement who had experienced earlier winters there, that the season was the poorest for many years, and this was confirmed by observers throughout Canada. At Fort Rae, activity was unquestionably both more widely distributed over the entire sky and more frequent than in the northern localities of Western Europe during the preceding three or four years, but in general retrospect the various types were much more frequently diffuse, lacking in robustness and definition and in the characteristically distinctive features by which the various auroral types are usually defined. In localities in the immediate vicinity of the maximum frequency zone, aurora in years of low solar activity may be characterised by these features rather than by reduction in frequency.

§ 103. *Quarter-hour intensity figures.*—On the basis of the intensity figures appearing against the observations during each quarter-hour of auroral activity a mean intensity figure has been assigned. From the nature of the phenomenon such quarter-hour figures could not be derived simply as the arithmetic means of the various intensities which had been noted during the period. For at each moment of observation several auroral forms of different brightness, and therefore requiring separate intensity figures, were usually in the sky at the same time, so that even for each observation a composite figure was needed to represent the major aspects of the activity. In turn, the quarter-hour mean was assigned on the basis of these composite figures in such a way as to produce a figure on the same 0 to 4 scale as its constituents, but representative of the main features which had appeared during the 15-minute interval.

In the schedules (one for each month) summarising these quarter-hour figures four letters *a*, A, *b*, *c* were used.

a was entered against quarter-hours during which the presence of aurora was observed, but, being heavily veiled by cloud, neither its intensity nor its form could be discerned.

A was assigned in conditions similar to those for *a* but when in addition the cloud was sufficiently thin or the aurora sufficiently strong for it to be described as bright. In subsequent use of these schedules a quarter-hour or hour of A has been taken as equivalent to an intensity figure $\not<2+$, which is accepted as the lower limit of bright aurora.

b denoted that aurora was observed but no details were noted. *b* naturally makes very infrequent appearance in the tables. It generally signified that some other job temporarily demanded the observer's attention.

c denoted that the sky was clouded or overcast and that the presence of aurora was not detected.

§ 104. *Monthly distribution of periods of bright aurora.*—The schedules of quarter-hour intensity figures are not reproduced, but have been used extensively for further analysis. In the first place, they provide the basis for an analysis of the month-to-month variation in incidence of aurora of various grades of intensity. The results of such an analysis are given in Table 94 in which the grouping of the quarter-hours

TABLE 94.—FREQUENCY OF $\frac{1}{4}$-HOURS OF VARIOUS AURORAL INTENSITIES.

Grouped Intensities.	Class of Aurora.	1932.					1933.							Total.
		Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	July.	Aug.	
Intensity $\nless$ 2 +	B	73	164	28	32	141	109	129	127	92	8	10	66	979
Intensity 3 − and 3	B′	34	62	11	15	71	53	45	64	31	5	5	36	432
Intensity 3 +, 4 −, and 4	B″	18	63	2	4	11	10	25	17	6	0	4	7	167
Number of nights	..	24	27	23	21	28	29	23	29	25	12	4	25	270

of average intensity 3 +, 4 −, and 4 was intended to segregate the very brightest (B″) periods from the merely very bright (B′) 3 and 3 − ; all occasions of intensity $\nless$ 2 + were classed as bright (B) aurora, *i.e.* the B class includes classes B′ and B″. Of the total number (5832) of all quarter-hours during which aurora was observed, only 979 (or 17%) could be characterised as B and of these only 167 (or 3% of the total) as B″.

Even without making adjustments for varying duration of darkness and for varying cloudiness throughout the auroral season, the monthly distribution of quarter-hours in each of the three classes B, B′, and B″ shows that the frequency of bright aurora was not even roughly in proportion to the average duration of aurora of all intensities in each month as shown by the last line of Table 92. Whereas the simple frequency or duration of aurora of all kinds was greatest in December, January, and February, the month of greatest frequency of all grades of bright aurora was September 1932; it was also the outstanding month for quarter-hours of the brightest aurora. Judged by the frequency of occurrence of this same class of B″ aurora, February 1933, August 1932, and March 1933 were the next best months, but in terms of all grades of bright aurora (class B) December replaces August 1932 as being intermediate in order between September and February and March.

In order to assess the significance of the crude frequencies of bright aurora in the classified intensities of Table 94, we have attempted to convert them into percentages of favourable occasions for observing these intensities. But it has been found impracticable to derive truly comparable measures for each month. To achieve this would require detailed consideration of those various factors (depending on variability of amount and type of cloud, duration of twilight, and, to a less extent, the age of the moon) which affect the assignment of intensity figures on a fairly large proportion of all nights. It is not feasible even to consider the number of quarter-hours of B aurora in relation to the number of quarter-hours of all aurora. For in a month like July 1933 there were 10 of the former and only 14 of the latter, an obvious and immediate consequence of the impossibility of being able to detect any but bright aurora during strong twilight.

Taking all factors into account in a general way, probably the only safe inference

TABLE 95.—DIURNAL FREQUENCY DISTRIBUTION OF ¼-HOURS OF AURORA: ALL INTENSITIES.

Hour G.M.T.		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total.
L.M.T.		16¼	17¼	18¼	19¼	20¼	21¼	22¼	23¼	00¼	01¼	02¼	03¼	04¼	05¼	06¼	07¼	
1932 Aug.	..	..	..	..	..	4 6	9 10 11 12	14 14 18 19	21 20 22 22	20 19 18 17	16 12 12 8	6 2	..	..	..	..	..	332
Sept.	..	..	..	1 1 2	6 9 10 11	12 10 14 18	18 19 21 21	22 23 22 21	22 21 20 22	22 21 22 19	19 19 18 17	15 13 10 6	2 1	..	..	..	..	550
Oct.	..	..	1 2	2 4 6 7	5 5 6 6	9 9 9 11	13 11 10 10	12 11 10 10	11 12 13 13	14 13 13 13	13 14 11 11	11 10 7 6	3 1 1 2	3 1 1 1	1 1	..	..	369
Nov.	..	2 3	4 3 2 2	5 5 5 7	9 8 5 7	9 8 9 8	8 9 9 10	10 11 14 16	15 15 14 12	14 15 15 15	12 11 12 12	11 12 11 9	10 7 6 6	6 6 6 8	11 11 10 8	6 4 4 1	..	503
Dec.	1 2	5 5 7 8	8 9 8 10	11 11 11 13	10 9 11 13	13 13 13 12	16 13 14 16	13 14 22 20	21 20 18 18	18 17 17 17	16 17 18 17	18 18 19 17	13 13 13 13	13 11 11 15	17 16 16 16	16 15 13 11	7 1 1	848
1933 Jan.	..	1 2 7 8	11 10 13 14	15 14 16 14	15 17 17 16	17 14 16 15	17 17 18 18	21 21 21 21	20 20 21 22	22 21 22 19	23 23 22 21	22 20 19 19	17 19 18 19	20 18 17 18	18 17 17 16	15 14 11 9	5	1010
Feb.	..	..	2 3 5	10 11 12 12	12 12 13 13	13 12 14 12	16 17 16 17	18 19 19 17	19 19 19 19	20 21 22 22	21 21 21 21	19 19 19 19	18 15 12 12	6 6 7 13	16 13 12 9	5 1 1	..	762
Mar.	..	..	..	..	4 7 6 9	13 13 15 16	15 14 12 16	19 19 20 23	24 24 22 24	24 23 22 24	23 23 22 24	24 25 22 22	14 11 7 6	4 1 2	..	..	..	638
Apr.	..	..	..	..	1 1 3	3 4 9 9	11 13 13 15	19 20 22 22	23 23 22 21	21 21 22 20	20 18 16 15	14 13 5 3	2 2	..	..	..	..	446
May	..	..	..	..	..	..	2	3 4 6 7	7 8 8 10	5 5 5 6	4 3 3 2	1	..	..	..	..	..	89
July	..	..	..	..	..	..	..	2 3	3 3 2 1	..	..	..	..	..	..	..	..	14
Aug.	..	..	..	..	..	2 3	4 5 8 11	13 13 13 16	17 15 15 16	18 17 16 15	15 13 10 8	7 1	..	..	..	..	..	271
Total	1 2	6 7 16 19	23 24 27 33	43 46 51 55	61 68 69 78	89 83 105 110	127 128 132 148	164 169 189 195	203 200 196 200	198 193 194 187	182 174 165 156	148 133 112 101	79 69 57 58	52 43 42 57	63 58 55 49	42 34 29 21	12 1 1	5832
Sept.–Mar.	1 2	6 7 16 19	23 24 27 33	43 46 51 55	61 67 68 75	86 79 90 92	103 100 100 108	115 118 128 128	132 131 127 130	134 131 133 129	127 128 124 123	120 117 107 98	77 67 57 58	52 43 42 57	63 58 55 49	42 34 29 21	12 1 1	4680
Aug. 1932 and Apr.–Aug. 1933	..	..	..	..	1 1 3	3 4 15 18	24 28 32 40	49 51 61 67	71 69 69 70	64 62 61 58	55 46 41 33	28 16 5 3	2 2	..	..	..	..	1152
Sept.–Oct.	..	..	1 2	2 5 7 9	11 14 16 17	21 19 23 29	31 30 31 31	34 34 32 31	33 33 33 35	36 34 35 32	32 33 29 28	26 23 17 12	5 2 1 2	3 1 1 1	1 1	..	..	919
Nov.–Jan.	1 2	6 7 16 19	23 22 23 26	31 30 32 34	34 34 33 36	39 35 38 35	41 39 41 44	44 46 57 57	56 55 53 52	54 53 54 51	51 51 52 50	51 50 49 45	40 39 37 38	39 35 34 41	46 44 43 40	37 33 28 21	12 1 1	2361
Feb.–Mar.	..	..	2 3 5	10 11 12 12	16 19 19 22	26 25 29 28	31 31 28 33	37 38 39 40	43 43 41 43	44 44 44 46	44 44 43 45	43 44 41 41	32 26 19 18	10 7 7 15	16 13 12 9	5 1 1	..	1400

TABLE 96.—DIURNAL FREQUENCY DISTRIBUTION OF ¼-HOURS OF BRIGHT AURORA.

Hour G.M.T.		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total.
L.M.T.		16¼	17¼	18¼	19¼	20¼	21¼	22¼	23¼	00¼	01¼	02¼	03¼	04¼	05¼	06¼	07¼	
1932 Aug.	..	..	..	..	..	1 1	1 2 3 5	4 4 4 5	5 2 5 5	5 6 7 4	2 1	1	..	..	..	..	..	73
Sept.	..	..	..	1	1 2 4 2	1 1 3 4	3 5 5 3	6 7 7 8	10 10 7 8	9 8 7 9	5 6 7 4	6 1 2 2	..	..	..	..	..	164
Oct.	..	..	..	1	1 1	1	1 1	1 1 1 1	3 4 3 1	1 4 1	1	..	..	..	..	..	..	28
Nov.	..	..	..	..	..	..	2	1 1 1 3	4 2 3 1	1 3 4 1	1 3	1	..	..	..	..	..	32
Dec.	1	2 3 3 2	3 3 3 3	1 2 3 4	4 2 2 1	1	2 1 2 1	1 3 6 8	5 5 7 5	3 6 3 5	2 2 4 4	5 2 2	1	1 1 1 2	1 3 1	1 1 1	..	141
1933 Jan.	..	1 1	2	2 1 1 2	1 1	1 2 4 6	2 4 4 4	4 3 2 3	3 5 3 5	6 4 7 3	6 5 2 1	1 1	2 2 1	..	..	1	..	109
Feb.	..	..	..	2 4 4 5	6 5 4 2	2 3 4 3	2 3 3 4	3 2 2 2	2 5 5 3	5 4 7 5	3 3 6 4	3 3 1	1 2 1 1	..	..	..	..	129
Mar.	..	..	..	..	1 3 3	3 3 3 4	5 5 5 2	2 5 4 4	6 10 4 5	6 9 6 2	1 4 3 5	2 3 4 1	2 1 1	..	..	..	..	127
Apr.	..	..	..	..	..	1 2 2 3	2 2 3 4	5 5 5 4	3 7 7 4	5 6 5 2	1 2 5 3	2 1 1	..	..	..	..	..	92
May	..	..	..	..	..	..	..	1 1 1	3	1	..	1	..	..	..	..	..	8
July	..	..	..	..	..	..	..	2 2	2 1 2 1	..	..	..	..	..	..	..	..	10
Aug.	..	..	..	..	..	..	1 1 2 3	4 5 6 10	5 6 6 2	3 3 3 1	2 1 1	1	..	..	..	..	..	66
Total	1	2 3 4 3	5 3 3 3	5 7 8 13	13 10 14 9	10 11 17 21	20 23 28 27	32 37 40 51	48 57 52 43	45 53 49 33	22 25 29 24	23 10 7 7	5 5 3 2	1 1 1 2	1 3 1	2 1 1	..	979
Sept.–Mar.	1	2 3 4 3	5 3 3 3	5 7 8 13	13 10 14 9	9 9 14 17	16 18 20 15	18 22 23 29	33 41 32 28	31 38 34 26	17 21 23 21	18 10 6 6	5 5 3 2	1 1 1 2	1 3 1	2 1 1	..	730
Aug. 1932 and Apr.–Aug. 1933	..	..	..	..	..	1 2 3 4	4 5 8 12	14 15 17 22	15 16 20 15	14 15 15 7	5 4 6 3	5 1 1	..	..	..	..	..	249
Sept.–Oct.	..	..	..	2	1 2 5 3	2 1 3 4	3 5 6 4	7 8 8 9	13 14 10 9	10 12 7 10	5 7 7 4	6 1 2 2	..	..	..	..	..	192
Nov.–Jan.	1	2 3 4 3	5 3 3 3	3 3 4 6	5 3 2 1	2 2 4 6	6 5 6 5	6 7 9 14	12 12 13 11	10 13 14 9	8 7 7 8	7 3 2	2 2 1 1	1 1 1 2	1 3 1	2 1 1	..	282
Feb.–Mar.	..	..	..	2 4 4 5	7 5 7 5	5 6 7 7	7 8 8 6	5 7 6 6	8 15 9 8	11 13 13 7	4 7 9 9	5 6 4 2	3 3 2 1	..	..	..	..	256

TABLE 97.—DIURNAL FREQUENCY DISTRIBUTION OF BRIGHTEST AURORA.
(Entries are numbers of ¼-hours of specified intensity.)

	Hour G.M.T.		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Intensity 2+	B	..	1 2 3 1	1 1 3 3	4 5 3 6	5 1 7 3	5 5 8 9	9 9 13 6	12 15 14 17	15 24 19 12	17 23 20 9	9 11 16 4	9 7 2 2	1 2 1 2	1	1	1 1	
Intensities 3− and 3	B′	1	1 1 2	3 2	2 5 5	6 7 6 3	2 4 5 10	8 9 10 11	15 13 18 24	20 21 25 22	22 24 24 19	9 8 9 15	11 3 5 5	3 2 2	1 1 1 1	1 2 1	1	1
Intensities 3+, 4−, and 4	B″	..	1	1	1 2	2 2 1 3	3 2 4 2	3 5 5 10	5 9 8 10	13 12 8 9	6 6 5 5	4 6 4 5	3	1 1				
Intensities ≮ 3−	B′+B″	1	1 1 1 2	4 2	1 2 5 7	8 9 7 6	5 6 9 12	11 14 15 21	20 22 26 34	33 33 33 31	28 30 29 24	13 14 13 20	14 3 5 5	4 3 2	1 1 1 1	1 2 1	1	1

from the B, B′, and B″ frequencies in Table 94 is that aurora in August and September 1932 and February, March, and April 1933 was more frequently stronger than in the other months of the year, and that of those five, September was the outstanding month. If we discount October as being the month of greatest uncertainty owing to high frequency of low cloud, the months at the other end of the scale of average auroral brightness are November, December, and January, with November unquestionably lowest (*cf.* § 86).

§ 105. *Diurnal distribution of frequency of aurora—all intensities.*—Excluding *a*, A, and *b* as indeterminate entries in the schedules (§ 103) of quarter-hour auroral intensities for each day, the number of all quarter-hours to which mean figures had been assigned were summed for each quarter-hour of the Greenwich hours 0 to 16 (*i.e.* from 16h zonal time in one day to 8h on the next morning) for all days

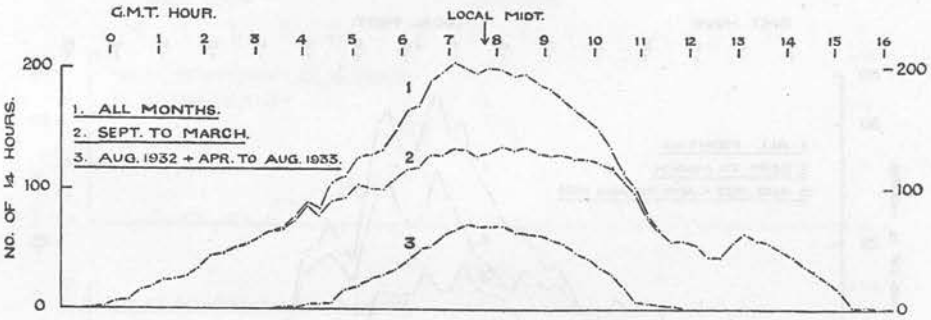


FIG. 26.—Diurnal frequency distribution of ¼-hours of aurora: all intensities.

of each month. These sums together with the totals for various groups of months are given in Table 95. These groups comprise:

(i) All twelve months during which aurora was observed;

(ii) The months September to March alone when the duration of darkness and twilight was favourable for at least four hours' observing before and after midnight;

(iii) The balance of the five months, August 1932, April, May, July, and August 1933, during at least some of which twilight was too strong even in the darkest hours to allow any confidence to be attached to the resulting distribution; and

(iv) Subdivision of the group of seven months September to March into the three groups, September and October representing autumn, November, December, and January representing mid-winter, and February and March representing spring.

The distributions of Table 95, which are represented in fig. 26, show that the frequency of aurora of all intensities is greatest in the hours immediately around local midnight. The frequency rises steadily during the late evening hours to a maximum which, on the average of the seven months September to March, is probably just after midnight, falls off at first gently to about 10h G.M.T. (*ca.* 2h local time) and then more steeply. The tendency to a recrudescence at 13h G.M.T. (*ca.* 5h L.T.) is shown separately in each of the four mid-winter months November to February and is probably real.

The time of incidence of the real maximum is not readily assessable largely because of the flatness of the distribution curve in the immediately post-midnight hours. But the inference to be drawn from the totals derived from the seasonal sub-grouping of the seven months September to March would appear to be that in autumn and spring the maxima are half an hour and about one hour respectively after midnight, whereas at mid-winter the maximum occurs one hour before midnight. This advance of the time of maximum in winter is similar to the corresponding phenomenon of short period irregular disturbance in the earth's magnetic field.

§ 106. *Diurnal distribution of occurrences of bright aurora.*—Table 96 shows for each month the diurnal frequency distributions of occurrences of quarter-hour intensities of $\nless 2+$ or A, *i.e.* of hours classed as B in § 104. Totals are given in this table for the same groups of months as in the preceding paragraph, and fig. 27 illustrates the frequency distributions for the three major groups there described.

It is clear that, as for simple frequencies of all types of aurora, the short interval centred approximately at local midnight is the most favourable time for bright forms. But much more conspicuously than for all-intensity occurrences those of bright aurora appear to have two maxima separated by an hour, the earlier occurring at 7h 15–30m G.M.T. or 23h 30–45m local time. When the seven months September to March are grouped seasonally as in the foregoing paragraph, the characteristic of an apparent reduction in frequency of B periods between these two maxima is found to be common to the autumn, mid-winter, and early spring months. Had the peculiarity of this double maximum appeared on either side of 7h instead of 8h G.M.T. an explanation might have been sought in the fact that a comprehensive

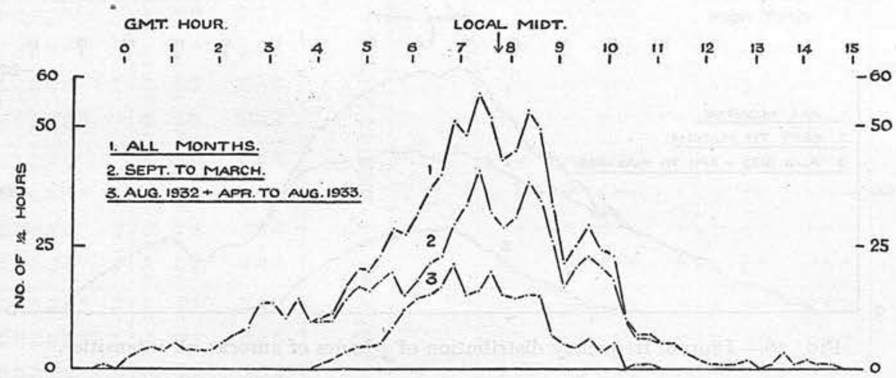


FIG. 27.—Diurnal frequency distribution of ¼-hours of bright aurora.

three-hourly meteorological observation was then made throughout the year. For at that time the attention of the observer would be required indoors for a few minutes with the possible consequence of a slight reduction in the number of bright aurora noted, either because sudden short-lived outbursts might have passed unobserved or—a more likely contingency—because a temporary and unconscious change would take place in the observer's standard of brightness owing to the necessity for adaptation of the eye to other work. It is clear from the steadily increasing frequency up to 7h 30–45m G.M.T. of B quarter-hours in the seven main auroral months September to March that neither of these possible spurious reactions of the meteorological observations seriously affected the observation of aurora.

For further light on this anomaly, separate frequency distributions have been formed for the various groups of quarter-hour intensity figures comprising the general class of bright aurora in Table 96. Table 97 shows these separate distributions for 2+ intensities alone, for 3− and 3 together (B′ aurora), for 3+, 4−, and 4 (B″ aurora), and for B′ and B″ together. The curves representing the last two of these four groups are plotted in fig. 28. The outcome of this segregation is to make it fairly certain that the double maximum can be attributed to accidental causes limited, in the main, to the group of 2+ intensities. Quarter-hours of B″ aurora have an unmistakable single maximum at 7h 0–15m G.M.T. and the combined frequencies of the B′ and B″ groups vary little from 6h 45m–7h 45m. It is probable that the pronounced double maximum in the 2+ group alone would be smoothed out if intensity figures in the next lower group 2 were included.

Taking all the facts into consideration, the general inference from the study of these diurnal distributions must therefore be that the most favoured time for bright aurora at Fort Rae is the 60-minute interval before 8h G.M.T., and more particularly in the quarter-hour 7h 15–30m G.M.T., *i.e.* about half an hour before local midnight.

Another characteristic of the distribution of bright aurora deducible from the data of Table 97 is better illustrated by rearranging the data as in Table 98. Here the entries are total numbers of occurrences for groups of months of quarter-hours of intensities $\nless 2+$ in the 60-minute intervals before and after local midnight. A similar set of frequencies for the selected occasions of B″ aurora is given in the last line of the table, all months being grouped together in one set of totals. The characteristic shown by the table, both for the B″ class of aurora and only slightly less systematically for the general B class, is that bright aurora is in general more likely to occur in any one hour before midnight than in the hour at an equal interval after midnight.

§ 107. *Hourly intensity figures.*—With the intention of using the data for correlation with measures of magnetic disturbance, auroral intensity figures were assigned to each Greenwich whole hour on the principle that the hourly auroral activity is primarily characterised by the most vigorous outbursts occurring within

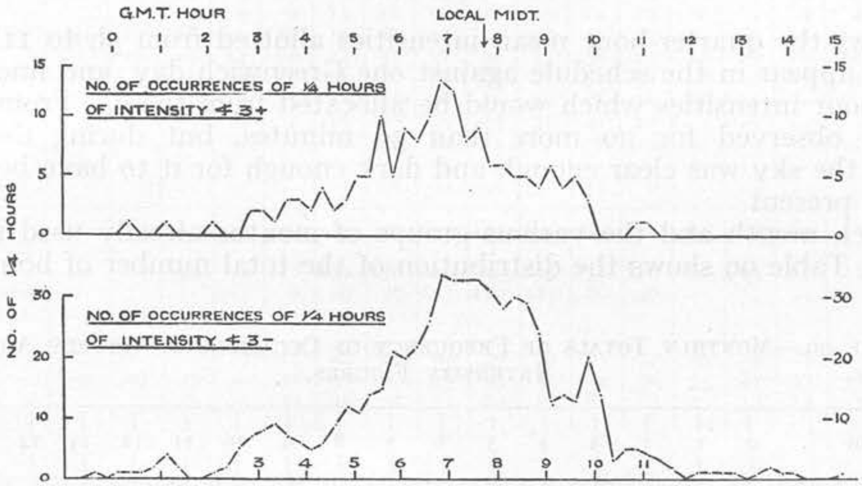


FIG. 28.—Diurnal frequency distribution of ¼-hours of brightest aurora.

the hour, whether they be of short or prolonged duration. From the schedules showing the average intensity allotted to each full quarter-hour, that figure was assigned to the whole hour which was the highest of the four such average intensities occurring in it. These hourly intensity figures were applied only to hours in which aurora was seen, or could have been seen had it been present, throughout the whole hour. In some incomplete hours (owing, *e.g.*, to cloud) an intensity was assigned, provided the period of uncertainty was not for more than a quarter-hour. If any quarter-hour had been allotted a 4, even though all the other quarters in that hour were completely uncertain, the whole hour was characterised by a 4; occurrences of A were treated as equivalent to $2\frac{1}{2}$, the lower limit of intensity associated with that letter. On those occasions when the highest mean quarter-hour intensity

TABLE 98.—FREQUENCY OF BRIGHT AURORA BEFORE AND AFTER MIDNIGHT.

	4 Hours	3 Hours	2 Hours	1 Hour	1 Hour	2 Hours	3 Hours	4 Hours
	Before Midnight.				After Midnight.			
Totals: All months .	47	92	136	208	190	109	64	20
Sept.–Mar. .	41	71	78	135	131	87	55	19
Sept.–Oct. .	9	18	27	46	38	29	13	2
Nov.–Jan. .	9	23	27	51	48	31	18	7
Feb.–Mar. .	23	30	24	38	45	27	24	10
B″ aurora: All months	12	15	32	43	26	19	8	2

taken to represent the whole hour included a + or − suffix to the numeral the sign was made equivalent to a $\frac{1}{2}$ and denoted in the resulting summary of total intensities by a dot after the number.

Briefly to recapitulate and illustrate the method outlined above for constructing this table, a hypothetical example might be as follows:—

G.M.T. Hour.	5h–6h	6h–7h	7h–8h	8h–9h	9h–10h	10h–11h
1.	2 0 1 3+	1 0+ 0+ 2	4 1+ 2 *a*	1+ 0+ 0+ A	2 2+ 0+ 1	3 1 0 0
2.	3+	2	4	2+	2+	3

Line 1 shows the quarter-hour mean intensities allotted from 5h to 11h G.M.T. as they would appear in the schedule against one Greenwich day, and line 2 gives the six whole hour intensities which would be allocated from these. From 10h to 11h aurora was observed for no more than 30 minutes, but during the remaining 30 minutes the sky was clear enough and dark enough for it to have been observed had it been present.

For each month and the various groups of months already used in preceding paragraphs, Table 99 shows the distribution of the total number of hours for which

TABLE 99.—MONTHLY TOTALS OF FREQUENCY OF OCCASIONS OF HOURLY AURORAL INTENSITY FIGURES.

Greenwich Hour .	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total.
1932 Aug.	..	..	..	..	..	7	12	19	23	20	16	6	..	..	..	..	..	103
Sept.	..	..	..	2	10	12	14	17	18	19	17	13	2	..	..	..	..	124
Oct.	..	..	..	3	3	4	7	8	8	11	9	6	2	2	1	..	..	64
Nov.	..	3	4	6	7	8	8	10	11	14	12	10	9	7	9	6	..	124
Dec.	(2)	6	10	13	11	13	13	15	18	17	15	15	14	12	16	15	7	212
1933 Jan.	..	10	12	12	16	16	18	19	19	21	21	17	16	18	18	15	5	253
Feb.	..	..	5	13	12	13	17	18	19	21	21	19	16	11	16	5	..	206
Mar.	..	..	..	..	7	13	14	21	21	22	22	21	11	4	..	..	..	156
Apr.	..	..	..	..	1	9	15	18	21	22	18	14	..	..	..	..	..	118
May	..	..	..	..	..	..	1	6	8	7	4	1	..	..	..	..	..	27
July	..	..	..	..	..	..	..	1	2	..	..	..	..	..	..	..	..	3
Aug.	..	..	..	..	..	1	8	13	15	16	12	5	..	..	..	..	..	70
Total	(2)	19	31	49	67	96	127	165	183	190	167	127	70	54	60	41	12	1460
Sept.–Mar.	(2)	19	31	49	66	79	91	108	114	125	117	101	70	54	60	41	12	1139
Aug. 1932 and Apr.–Aug. 1933.	..	..	..	..	1	17	36	57	69	65	50	26	..	..	..	..	..	321
Sept.–Oct.	..	..	..	5	13	16	21	25	26	30	26	19	4	2	1	..	..	188
Nov.–Jan.	(2)	19	26	31	34	37	39	44	48	52	48	42	39	37	43	36	12	589
Feb.–Mar.	..	..	5	13	19	26	31	39	40	43	43	40	27	15	16	5	..	362

hourly intensity figures have been assigned; Table 100 gives the sums of these intensity figures. Both these tables are separately instructive, but for our immediate purpose the significance of their contents can be more readily appreciated by dividing the summed intensities for each hour by the number of contributing hours. This is done to form Table 101 in which all the hours of each month have been grouped to give a monthly mean hourly intensity figure, and also to form Table 102 in which, for each of the groups of months, a mean hourly intensity figure is given for each hour.

As has been explained, *a* or A was entered against each quarter-hour during which the presence of aurora could be detected, but when no determinate intensity could be assigned owing to cloud. In the method adopted for extending to hourly intensity figures, account could be taken of the A's but not the *a*'s. It would therefore not be strictly accurate to say that cloud affected all the grades of hourly intensities equally. But since the total number of occasions of neglect of *a* and use of A was small, it may be assumed that the hourly mean intensity figures of Tables

TABLE 100.—MONTHLY SUMS OF HOURLY AURORAL INTENSITY FIGURES FOR EACH HOUR.
(a "·" has the significance of a ½.)

Greenwich Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total.
1932 Aug.	..	..	..	..	..	10	27	40·	53·	47·	27	5·	..	..	..	..	..	211
Sept.	..	..	..	4	22·	21	31·	48	54	55	45	28	2	..	..	..	..	311
Oct.	..	..	..	3	5	6	13	14	16	25	16	9	3	2	1	..	..	113
Nov.	..	2	4·	6·	9	13	12	16·	18·	25·	24	15	12	8	9·	4·	..	180·
Dec.	(4)	13	18	19	19	19	20·	28	37·	37·	30	29·	20	19	23·	19·	6·	363·
1933 Jan.	..	12·	14	14	20·	24·	34·	31	39	42·	38	25·	20	20·	20·	14·	3	374·
Feb.	..	..	5	26·	27	21·	28	33	38·	42	41	34	18·	10·	13	3	..	341·
Mar.	..	..	..	..	15	25	30·	38·	46	47	40	35	17	5	..	..	..	299
Apr.	..	..	..	..	2	18	30	35·	43	41·	34·	22	..	..	..	..	..	226·
May	..	..	..	..	..	..	2	10	13	7·	6·	3	..	..	..	..	..	42
July	..	..	..	..	..	..	..	3	6	..	..	..	..	..	..	..	..	9
Aug.	..	..	..	..	..	1	18	34	35	31	18·	6	..	..	..	..	..	143·
Total	(4)	27·	41·	73	120	159	247	332	400	402	320·	212·	92·	65	67·	41·	9·	2615
Sept.–Mar.	(4)	27·	41·	73	118	130	170	209	249·	274·	234	176	92·	65	67·	41·	9·	1983
Aug. 1932 and Apr.–Aug. 1933.	..	..	..	..	2	29	77	123	150·	127·	86·	36·	..	..	..	..	..	632
Sept.–Oct.	..	..	..	7	27·	27	44·	62	70	80	61	37	5	2	1	..	..	424
Nov.–Jan.	(4)	27·	36·	39·	48·	56·	67	75·	95	105·	92	70	52	47·	53·	38·	9·	918·
Feb.–Mar.	..	..	5	26·	42	46·	58·	71·	84·	89	81	69	35·	15·	13	3	..	640·

101 and 102 are not sensibly affected by varying conditions of cloud from month to month. Since, moreover, the hour-to-hour variation of cloudiness during the dark hours was in the mean inconspicuously small, the diurnal variation of mean hourly intensity will also not be affected by this peculiarity in the assignment of intensity figures. Hence any inferences to be drawn from Tables 101 and 102 concerning the seasonal and diurnal variations of auroral intensity should be more free of the effects of non-auroral factors than the inferences from earlier tables.

TABLE 101.—MONTHLY MEAN HOURLY AURORAL INTENSITY FIGURES AND NUMBER OF CONTRIBUTING HOURS.

	1932.					1933.						
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	July.	Aug.
Mean intensity figure	2·05	2·51	1·77	1·46	1·71	1·48	1·66	1·92	1·90	(1·56)	(3·00)	2·05
No. of contributing hours	103	124	64	124	212	253	206	156	118	27	3	70

§ 108. *Seasonal variation of average intensity.*—Discounting May and July 1933 as having too few complete hours of aurora to be adequately represented by a mean intensity figure, the monthly mean values in Table 101 confirm the inference from Table 94 that September was the most active and November and January the least active of the twelve months represented in that table. In this respect auroral intensity and local magnetic disturbance as judged by the $HR_H + ZR_Z$ criterion are in agreement (see Table 85). As a further grouping, September and the August of both years together with March and April are in one class of high auroral intensity, while November, January, and February fall in the class of low values, with October and December intermediate. This is all in general accord with the rank order based on indices of local magnetic disturbance.

§ 109. *Diurnal variation of average intensities.*—Table 102 shows for groups of months the average hourly intensities got by dividing the summed intensities of Table 100 by the number of contributing hours in Table 99. On the average of all

TABLE 102.—MEAN HOURLY AURORAL INTENSITY FIGURES FOR EACH HOUR IN GROUPS OF MONTHS.

Hour G.M.T.	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16
(1) All months	1·45	1·34	1·49	1·79	1·66	1·95	2·01	2·19	2·11	1·92	1·67	1·32	1·20	1·12	1·01	0·79
(2) Sept.–Mar.	1·45	1·34	1·49	1·79	1·65	1·87	1·94	2·19	2·20	2·00	1·74	1·32	1·20	1·12	1·01	0·79
(3) Aug. 1932 and Apr.–Aug. 1933.	..	..	..	..	1·70	2·14	2·16	2·18	1·96	1·73	1·40					
(4) Sept.–Oct.	..	..	1·40	2·12	1·69	2·12	2·48	2·69	2·67	2·35	1·95	1·25	1·00	1·00		
(5) Nov.–Jan.	1·45	1·40	1·27	1·43	1·53	1·72	1·72	1·98	2·03	1·92	1·67	1·33	1·28	1·24	1·07	0·79
(6) Feb.–Mar.	..	1·00	2·04	2·21	1·79	1·89	1·83	2·11	2·07	1·88	1·72	1·31	1·03	0·81	0·60	

twelve months in which aurora was observed, 7–8h G.M.T. was the hour of highest average intensity in our connotation of this phrase. This agrees with earlier conclusions from the diurnal distribution of bright aurora (see §§ 105–106). For the seven months September to March the single hours before and after midnight are almost equal, and from the remaining groups 7–8h is the highest by a small margin. But, in contradistinction with the diurnal distribution of frequencies of aurora of all intensities (see § 105), the subdivision of the seven-month group shows that the maximum intensity tends to be later in the mid-winter than in the autumn and spring months. It is not possible to decide how far this may be attributed to the method of deriving the mean intensity figures here used, or how far it is a result of grouping four 15-minute periods into hours which are not measured from local midnight. But, by themselves, the results of Table 102 are probably not sufficiently independent to warrant their acceptance in preference to the conclusions from § 105.

§ 110. *General note on hourly intensity figures.*—Since it is likely that the majority of other Polar Year observers will be concerned less with the behaviour of quarter-

TABLE 103.—MONTHLY DISTRIBUTION OF HOURLY AURORAL INTENSITY FIGURES.

Intensity Figure.	1932.					1933.							Total.	Percentage of Total Number.
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	July.	Aug.		
4	6	25	..	2	2	5	7	3	..	..	..	..	50	3
3	28	35	7	7	44	28	33	42	23	3	3	20	273	19
2	39	44	35	47	73	70	62	52	61	10	..	33	526	36
1	20	16	22	47	62	111	77	53	33	11	..	17	469	32
0 +	10	4	..	21	31	39	27	6	1	3	..	..	142	10

hour auroral intensity figures than with figures covering 60-minute intervals, two further tables are given summarising the monthly distribution of hourly intensity figures (Table 103) and their distribution throughout the dark hours (Table 104). One or other of the five figures 0 + to 4 were assigned (according to the rules of § 107) to 1460 hours. Of these only 50 or 3% were 4's and 78% were 0 +, 1, or 2. Twenty-five of the 50 hours of 4 occurred in September; at the other extreme January had the highest proportion both of 1's and 2's.

Though not intended to contribute fresh information on the question of the diurnal distribution of aurora of different intensities, it is of interest to note that Table 104 confirms local midnight as the most likely time of occurrence of moderate or bright aurora—that is, of intensity 2 or greater. For if the distributions of the three intensities 2, 3, and 4 be grouped together, the composite distribution has equal frequencies for the two pairs of hours on either side of 8h G.M.T. Any inferences about the distribution of hours of weak aurora are probably too intimately bound up with the difficulty of assigning intensity figures in twilight to be of significance.

TABLE 104.—FREQUENCY OF OCCURRENCE OF HOURLY AURORAL INTENSITY FIGURES: ALL MONTHS TOGETHER.

Intensity Figure.	Hours G.M.T.																	Total.
	–0	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	
4	..	..	..	..	2	1	10	9	12	8	7	..	1	..	..	..	..	50
3	1	4	4	7	14	14	23	40	51	54	30	20	5	2	3	1	..	273
2	..	3	8	16	23	38	48	61	81	82	73	50	14	13	8	7	1	526
1	1	7	8	14	20	31	37	50	35	41	54	48	41	26	36	16	4	469
0+	..	5	11	12	8	12	9	5	4	5	3	9	9	13	13	17	7	142

§ 111. *Twenty-seven-day recurrence interval in aurora.*—Using the variety of statistical measures of auroral activity already formed for the inquiries of foregoing paragraphs, attempts have been made to demonstrate the existence of several well-

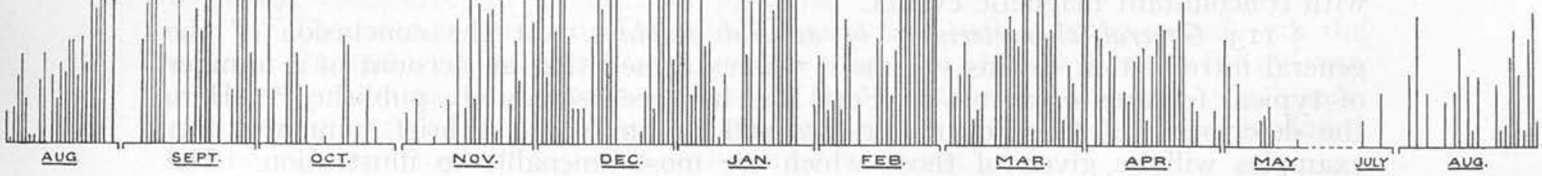


FIG. 29.—Summed hourly intensity figures for each day illustrating recurrences of auroral activity and quiet.

defined recurrences of which use was made when deciding on the periods of occupying the substation for photography. As in all such investigations which require the representation of a complex phenomenon by a single number, the results have been only partly successful. Ideally for such a purpose we should require a composite character number which would integrate over each night (1) the area of sky covered by the aurora, (2) its brightness, (3) its general vigour of movement, and (4) its duration, as well as take into account such additional factors as colour, clear-cutness, proportion of structured to homogeneous forms, and altitude, all of which contribute to distinguish the auroral activities on successive evenings. None of the measures utilised in earlier paragraphs provides adequate numerical equivalents of all of these aspects; the simplest approximation is probably given by the sums of the hourly intensity figures for each evening and these are plotted in fig. 29. In this figure prominent recurrences, both of absence of aurora and of great activity, are clearly recognisable in August and September and again from December to April, during which latter months there were at least two concurrently active periods. One conspicuous feature of fig. 29 is the apparently systematic diminution in length of the tallest clusters of ordinates starting at December 26 and continuing through January and February into March. This cannot be interpreted as indicating the mode of decay of auroral activity on successive recurrences; for those tallest ordinates derive from at least two overlapping and concurrent cycles of activity so that they are not at regular 27-day intervals. The reduction in summed hourly intensities which the ordinates represent is rather to be regarded as a function of decreasing duration of darkness. This could not readily have been allowed for by using average instead of summed figures, because on such a basis an hour of intensity 3 on one day would have appeared with the same ordinate as ten hours of the same intensity on another day.

§ 112. *Summaries of descriptions of representative displays.*—As has already been explained in § 97, the observational material on which the foregoing discussion is based is detailed and therefore extensive. An account of an individual night's display not infrequently occupies as many as 15 foolscap pages, much of the description being in an improvised shorthand for speed in dictation. From the viewpoint of interpretation and discussion there is the further inconvenience that the position of a large majority of the auroral forms is defined with reference to their stellar background, so that before the orientation and altitude of these forms relative to the station can be approximately determined it is necessary to use a planisphere adapted to the latitude and local time of Fort Rae.

As a preliminary to the detailed study of characteristics of auroral displays, however, and more especially before any inquiry could be undertaken into possible relationships between aurora and magnetic phenomena, it was considered expedient to summarise a number of representative displays, transforming in the summaries all positions given with reference to stars into approximate azimuths relative to the station.

It may be that examples of such summaries would provide just sufficient information about auroral events at Fort Rae on some representative nights as would allow anyone to decide how far any particular line of inquiry might be profitably undertaken. Summaries of the detailed notes for the period 1932 August 8 to September 17 are therefore given in § 124. They will also be referred to later in this discussion when describing some general features of aurora as well as in connection with concomitant magnetic events.

§ 113. *General characteristics of auroral displays.*—At the conclusion of the general introduction to this volume it was explained that an account of a number of typical features of aurora at Fort Rae has been separately published.* Here the description of these characteristics will be limited to a brief summary, but examples will be given of those which are most amenable to illustration. The characteristics may be summarised as follows:—

(i) Throughout the year a very large proportion of all aurora observed was (*a*) weak and thin, and (*b*) lacking in clear-cut definition of form. Taken in conjunction with the very high frequency of appearance during 1932–33, it is inferred that at least at places near the auroral zone low solar activity is accompanied by a reduction in robustness, vigour, and definition of form rather than in frequency of occurrence.

(ii) Though diffuse homogeneous arcs very frequently persisted for several hours in the same part of the sky with spasmodic deterioration to glows, their formation at other times was the first stage in a regular development, summarisable:—

$$\left.\begin{matrix}\mathrm{HA} \\ \rightarrow \mathrm{HB}\end{matrix}\right\} \rightarrow \left.\begin{matrix}\mathrm{RA} \\ \mathrm{RB}\end{matrix}\right\} \rightarrow \mathrm{Cn} \rightarrow \mathrm{R} \rightarrow \mathrm{D} \rightarrow \mathrm{C},$$

where

HA = homogeneous arc	D = drapery
HB = homogeneous band	C = corona
RA = rayed arc	DS = luminous surface
RB = rayed band	Cn = curtain
R = ray (or rays)	G = glow.

* See fourth paper on p. 15 of Introduction.

Such a development of form was invariably accompanied by a migration of the activity from the lower or middle into the upper sky, and frequently by a change of colour from the usual greenish yellow to red, crimson, or purple. The aurora was most active and highly coloured just before and frequently during the corona stage, thereafter degenerating to diffuse R.

(iii) Outbursts of activity such as those just described frequently occurred in quick succession with intervening short periods of rapid dispersion. An evening's display was characterised by the frequency or absence of such outbursts.

(iv) Coronas were invariably the most fleeting of all auroral forms at Fort Rae, lasting for a very few seconds at most; the converging rays constituting the corona were seldom, if ever, stationary during its existence; they were observed to rotate both clockwise and anti-clockwise round the centre.

(v) Wave and ray progressions along RB or Cn were more frequent from west to east than in the opposite direction in the proportion of about 4 to 1. Movements in both directions in the same curtain were not uncommon.

(vi) After particularly violent and isolated outbursts of the type described in (ii), the degeneration from C to diffuse Cn and R was frequently followed by a period in which the whole sky was covered with a confused tangle of rayed luminosity from which all colouration other than the basic greenish yellow had disappeared. This either slowly dissipated or was swept clear by a fresh RA or RB from near the horizon.

(vii) In a transition from HA to RA, rayed structure developed first at the extremities of the arc; conversely, when RA reverted to HA, the constituent rays persisted longer at the extremities.

(viii) Movements of HA and RA were generally in a direction transverse to their length.

(ix) There was a tendency for repetition of particular characteristics of displays on successive evenings; in some instances the repetition skipped one evening. In a less rigorous way there was a tendency for the auroral events constituting a display to repeat themselves at intervals of 27 days.

(x) The average position of the first auroral arcs each evening varied with the season. In mid-winter the arcs lay across the magnetic north sky, but in the autumn and spring months they almost invariably first appeared in the east, south-east, or overhead sky. This apparent seasonal variation is probably an effect produced by the varying length of day on a real diurnal variation.

(xi) Structured aurora was more evanescent in twilight than in darkness; quiet arcs were usually the first forms to be observed in evening twilight and persisted longer into the morning.

(xii) Throughout the year no pulsatory forms or flaming aurora were observed.

(xiii) Examples of clear-cut isolated R were rare.

(xiv) No aurora was observed by eye to have penetrated to unusually low levels, and there were no sound accompaniments in any display.

§ 114. *Notes on, and examples of, some characteristic modes of auroral behaviour at Fort Rae.*—(*a*) Persistent quiet arcs while intense activity was in progress in other parts of the sky. This was a fairly common feature illustrated by the display of 1932 September 6, when a narrow quiet HA remained low across the south sky for at least five hours, though at times enveloped in R, D, and Cn activity which spasmodically filled the whole sky. The presence of the HA was first noted at 5h 33m G.M.T. and thereafter at intervals to 10h 20m.

(*b*) Evolutionary development from quiet homogeneous arcs to coronas. A typical case was that of September 5, 7h 52m to 8h 4m. Further examples are given in the summaries of displays in § 124.

(*c*) Outbursts of activity culminating in corona and subsequent clearance. Examples of rapid developments of violent activity from comparatively quiet conditions following one another in quick succession with short intervening lulls are easily discerned in the representative displays summarised in § 124. A typical example is that of 1932 August 26 with three separate outbursts between 5h 48m and 6h 15m culminating in C at 5h 50m, 5h 58m, and very active Cns at 6h 12m.

On August 27 as many as six C formed or tended to form between 7h 59m and 8h 11m. On the next evening four complete or partially developed C formed between 5h 43m and 5h 50m, and later that same evening C formed six times between 7h 42m and 8h 5m indicating so many fresh outbreaks of activity.

(*d*) Modes of sky clearance after strong activity. The most usual sequel to a quick succession of vigorous waves of activity was that the entire sky was left covered with masses of confused and diffuse R which frequently degenerated into a glow. The display of September 27 illustrated the phenomenon at 10h 4–7m. In general, such widespread structured luminosity slowly dispersed, but on occasion the process of clearing the sky was hastened by an arc forming near the horizon and sweeping all the residual luminosity before it. Alternatively the luminosity itself coalesced around one edge to form a rough arc, which moved slowly over the sky, leaving the area traversed free from aurora. Examples of those two modes of clearance occurred on 1932 September 6 and on August 28 of the same year. On the latter date (at 7h 20m) the north-western edge of the aurora apparently moved up through the zenith, sweeping the luminosity into the south-eastern sky.

(*e*) Time of occurrence of coronas. Judged by the summary of occurrences in Table III, during the two months August and September 1932 when C were probably more frequent than at any other time, the 60-minute interval 7–8h G.M.T. was the most common for their formation.

(*f*) Transience of coronas. The preceding notes relating to waves of activity with their culminations in C illustrate the short-lived nature of the latter. In particular, in such a display as that of 1932 August 28 a C forming at 5h 45m 0s G.M.T. had been dispersed and reformed from a fresh convergence of R and D by 5h 45m 45s G.M.T. Immediately after 8h on the same evening three C formed and dispersed within two minutes. The actual life of such C in their complete form seldom exceeded a few seconds; frequently the corona formed, dispersed, and reformed immediately as, *e.g.*, on September 26 at 7h 24m.

(*g*) Tendency of coronas to repetition about the same time on consecutive evenings. On many evenings, occasionally for weeks at a time, no C were observed; in relation to the great frequency of other structured forms they were a comparatively rare phenomenon in most months. Though no definite numbers can be given it is probable that the total duration of all coronas observed at Fort Rae did not exceed ten minutes whereas aurora of one type or another was observed for upwards of 1500 hours. If in these circumstances C appeared about the same time to within a few minutes on consecutive evenings, or with a skip of one or two evenings, there is ground for regarding the reappearance as indicating a recurrence tendency in this particular auroral form, more especially, be it noted, when within two days C were observed as early as 4h 41m G.M.T. (1932 September 21) and as late as 10h 45m (September 22).

Examples:—

(i) On consecutive evenings:—

1932 August	27 and 28	.	8h 1m and 8h 50m: two occasions.
September	9 and 10	.	9h 2m, 9h 35m, and 10h 3m: three occasions.
	17 and 18	.	6h 30m.
	19 and 20	.	6h 58m.

(ii) With a skip of one evening:—

1932 August	26 and 28	.	5h 48m.
	28 and 30	.	7h 13m and 7h 42m: two occasions.
September	13 and 15	.	7h 2m.

(*h*) Position of radiation point of coronas. Occasionally it was practicable to note the approximate positions of coronas (C) by reference to their stellar background. With the time of appearance accurately known it was therefore possible to compute the altitude and elevation of their radiation points to within a few degrees. This has been done for a number of C observed in the two months August and September 1932, and the arithmetic mean from 22 positions is: azimuth from the south 41·5°, altitude 81·5°. With these may be compared the co-ordinates of the magnetic axis pole as given by the all-day values of declination and inclination at the surface, viz. D = 37·5° and I = 82·6°, but no rigorous inference can be drawn from these two sets of values. If the mode or the median of the 22 altitude values were accepted in place of the arithmetic mean, the altitude of the radiation position would approximately coincide with the value of I, but the azimuth would be more westward, 60–65° from south. Moreover, for strict comparison the magnetic field values should be those appropriate to the disturbed conditions which invariably accompanied C. It is perhaps not even admissible indiscriminately to relate a mean position deduced from various C to average magnetic conditions. For there is evidence that the perspective centres of C are not fixed even within a few hours on an individual evening. It has not so far been possible to deduce whether any relationship exists between the intensity of associated disturbance and variability of C positions.

(*i*) Two coronas observed simultaneously. Bearing on this same matter, it should be mentioned that the observations contain reference (*e.g.* 1932 September 30, 8h 17m) to the simultaneous formation of two C.

(*j*) Direction of rotation of corona rays. Even in their fleeting life, C were seldom stationary phenomena. The constituent R rotated violently around the radiation point. Both anti-clock and clockwise rotations were observed, but in the two months whose records have been most closely scrutinised anti-clockwise rotation (as seen from below) was much the more common. Both directions of rotation were observed in coronas appearing within a few hours of each other.

(*k*) Ray structure at extremities of HA. Occasions when R tufts appeared in an otherwise quiet and structureless arc were comparatively frequent. Almost invariably the tufts formed at one or other of the extremities of the arc and more frequently at the western than the eastern extremity. Records of R at the western limb of HA were made on January 2 at 1h 30m, January 3 at 2h 45m, and January 25 at 3h 20m. Conversely, in the change from RA to HA forms, R structure persisted longest at the extremities of the arc; at 1h 15m on January 23 such persistence at both limbs was noted. An HA on September 13 at 4h 15m was observed to have R tufts at both ends.

(*l*) Wave and ray movements along RA, RB, Cn, and D. Whether one or other of these forms was stationary or moving bodily across the sky, internal movements were very frequently in progress at the same time. These movements took two forms: (i) progressions of waves along the length of the arc, band, or curtain as if bundles of contiguous rays acted in consort to advance momentarily out from the general plane of the aurora, and (ii) series of extremely rapid waves of luminosity following in quick succession along the aurora as if constituent rays temporarily absorbed the illuminating energy from adjacent rays and transmitted it to the contiguous rays on the side in which the waves were moving.

From a number of representative displays estimates were made of the relative frequency of westward and eastward movements, both the (i) and (ii) classes of movement being grouped together. In 196 cases in which the direction of movement was specifically mentioned, 131 were directed WE., 41 EW., and in the remaining 24, to-and-fro movements were in progress simultaneously. All of these cases occurred in displays between 1932 August 14 and September 26.

(*m*) Repetition of distinctive features of auroral displays about the same time on successive evenings. Without reproducing the detailed observations, illustrations of repetition cannot readily be given except in a few clear-cut instances. This has already been done for coronas, and therefore for the times of culmination of the most active phases of a number of displays. Further examples of a similar kind might be quoted from the observations later in the year. About the same time (6h 50m–7h 15m) on the evenings of February 23 and 24 the sky was filled with violent curtain activity; similar concentrations occurred on February 26 and 27 between 5h 35m and 6h, and again on March 2 and 3 between 7h 20m and 7h 25m.

The displays of 1932 August 18 and 19 illustrated a repetition of a different type. On those two evenings aurora was observed to begin about the same time and in the same parts of the sky. It took the form of multiple arc systems overhead or slightly to the south of the magnetic prime vertical plane. On both evenings the early behaviour of these arcs was also similar. Vaguely sinuous movements passed along them, and at times they split longitudinally into fibrous filaments which subsequently recombined to form a single arc.

Again, on two such displays as December 28 and 29 repetition of detail was strongly suggested by the almost identical times (13h 40m G.M.T.) of disintegration of HAs which had been very persistent in the earlier stages of both displays. Similar examples were observed on December 31 and January 1. From the start of the display (0–1h G.M.T.) till 5h on both evenings the aurora took the form of HAs or RAs confined to the north sky. A lull shortly after 5h was followed by renewed activity in the south-east sky, beginning at 6h 55m on the 31st and 6h 35m on the 1st. The resemblance in general trend of the displays on these evenings might be extended to January 2, when activity was almost wholly limited to the north sky till 6h, after which it moved overhead and into the high south sky. If, as we have suggested in an earlier paragraph, a diurnal variation exists in the position of the main auroral forms, these phenomena are to be regarded less as a repetition of characteristics than as a manifestation of such a diurnal variation. In this event the whole variation is to be interpreted as being delayed by two or three hours on the two evenings following January 2. For on January 3 and 4 the migration of the aurora from north sky into the overhead and south sky was deferred to 8–9h G.M.T.

Somewhat different evidence for persistence of auroral features on two successive nights is provided by such a pair of displays as those of January 8 and 9. Both before and after those dates aurora had been first observed as soon as twilight was weak enough (say 1h 30m G.M.T.), but though the sky was almost cloudless in the early evening of both January 8 and 9, no aurora was observed till 3h 30m on the 8th and 3h 15m on the 9th. After a short interval of indifferent activity, a lull followed at 4h on both evenings; subsequent periods with no aurora occurred between 9h and 10h.

The displays of 1932 August 8 and 9, as summarised in § 124, illustrate another form of day-to-day recurrence tendency extending in a general way to the whole of the night's activity. Both displays began between 4h 30m and 5h G.M.T. with band or arc forms in the south or south-eastern sky. These continued till about 6h when there was a short lull. In the first 20 minutes after 6h on both nights arcs appeared across the overhead sky, and these in turn dissipated to be followed by another interval of weak aurora. During the hour between 6h 30m and 7h 30m the most active phases of both evenings occurred, the culmination in C in this period on the second evening being an intensification of a similar trend on the 8th. On both evenings a further lull occurred about 7h 50m, followed by another outburst which again was more intense on the 9th; the aurora was last observed between 8h and 9h on both evenings.

Later on in the same month the displays of August 19 and 20 were both protracted but almost uniformly poor, with few distinctive features throughout the whole evening. This type of similarity was common and formed the counterpart of other pairs or sets of consecutive evenings on which the aurora was very bright and active.

Finally, it should be mentioned that one of the most common forms of aurora at Fort Rae was a straggling diffuse arc extending from horizon to horizon. At times such arcs appeared to be homogeneous, but more frequently they were rifted and irregularly striated along their length. From measurements made from photographs of a few such arcs it is likely that on many occasions they were really the under-edges of draperies, the vertical extension of whose constituent rays could not be seen because of their steep angle to the horizontal. On batches of successive evenings this particular type of extensive but quiescent, low-intensity, diffuse aurora was so common that its absence could be regarded as unusual. If two such evenings followed each other the phenomenon could reasonably be considered as another form of repetition. Two such displays occurred on April 6 and 7, when few if any arcs extended to both horizons, and most of the activity took the form of scattered, broken R, RB, and Cns—the aurora indeed was "localised" in comparison with that of most other displays.

(*n*) Recurrence of distinctive features of auroral displays after 26 to 28 days. What we are concerned with here is not the fact that displays on three or four consecutive evenings are frequently followed, after an approximately 27-day interval, by another batch—this is well established and was indeed made use of in manning the substation for photography; we are suggesting that peculiarities of aurora on one or more evenings were repeated 26 to 28 days later so as to give a generic if not a detailed resemblance. Examples of this type of recurrence were more noticeable in the winter and spring months than in autumn, though this may be a spurious effect arising from the greater detail noted in the earlier months of observation obscuring the general trend. If only in such broad and negative features as unduly delayed time of start with subsequent absence of any outstanding characteristics such as intervals of bright Cn or D formation, the displays on the following dates illustrate this recurrence tendency: January 4 with February 1, January 8 with February 3, January 10–11 with February 6–7, and February 8–10 with March 7–8.

(*o*) Some miscellaneous occurrences.—(i) Usually an extensive arc form moved bodily transverse to its length in one direction: on August 19 (at 6h 38m) an HA across the south sky was observed to move quickly back and forward across Lyra transverse to itself. During the oscillatory movement the arc showed no structure, but a minute later rayed structure developed A similar phenomenon was observed on August 24 (at 6h 20m).

(ii) Instead of stretching from horizon to horizon, RB were frequently confined to one part of the sky. Occasionally the band assumed a horse-shoe shape. Examples occurred on September 15 (8h 57m), September 17 (8h 59m), and September 19 (9h 51m). It is of interest to note the close agreement in time on the first two of these dates; at the same time on the intervening evening, September 16, activity was almost absent. Further examples in that same month occurred on September 22 (at 9h 48m) and on September 26 and 27, though in these displays the RA had developed into a Cn or D before becoming horse-shoe in form.

(iii) On August 30 (at 5h 10m) two parallel arcs (probably RA), which were almost but not quite contiguous, had wave movements travelling simultaneously from west to east along them. The passage of the waves left the two arcs amalgamated.

(iv) Notes on unusual colouration effects occur frequently. For example, on August 28 (8h 57m) and August 30 there were frequent references to the entire length of rays constituting Cn or D being coloured purple-red; and on August 30 (7h 54m) the colour in a drapery changed from all red to all green and *vice versa*.

(v) Though more appropriate to a discussion of the results of photographic measurements, it is worth mention that arcs (both RA and HA) were occasionally noted as lying more athwart than orthogonal to the magnetic prime vertical plane through the station. One such example (RA) was observed on September 22 (at 10h 35m), another (perhaps HA) on January 24 (at 14h 15m) with a possible recurrence on the following day.

(vi) It has been explained that the formation of C was usually followed almost immediately by their dispersal into bundles of constituent long R or D which rapidly became diffuse. In two such displays as those of August 28 (at 5h 45m) and August 30 (at 7h 39m) the C after formation spread out into D elongated along the magnetic prime vertical plane. After some further activity in the drapery, the corona reformed and the same phenomenon was repeated a few minutes later.

§ 115. *Relationships between aurora and magnetic disturbance.* (a) *General note.*—Since the auroral material available from Fort Rae includes a great number—about 4700—of pairs of simultaneous photographs for parallactic measurement as well as the eye observations on which the discussion in preceding sections has been based, it is possible to investigate relationships with corresponding magnetic phenomena at Fort Rae from two different angles. The results from the analysis of the photographic material will be published later; they are necessarily less comprehensive than those derived from the eye observations. For, to serve their best purpose for subsequent measurement, the auroral forms which were photographed were in general selected as being the brightest, or steadiest, or most clean cut in the sky. At the same instant much other activity was commonly in progress in other parts of the sky. Moreover, the camera could take account of only 40 square degrees of sky at any one time. Hence the photographs were necessarily unrepresentative and probably selective of these auroral forms, which, by reason of their relative quiescence, were least effective in producing those types of disturbance in the earth's field which are most amenable to description and numerical treatment.

On the other hand, the detailed eye observations are troublesome to handle; their cumbersomeness increases with the amount of detail in the descriptions of each display; they generally require to be much simplified and summarised before correlation with other phenomena can be begun (§ 112). After such adaptations have been made, the data can be treated in at least three ways:—

(i) Statistically;

(ii) By selection of specific occurrences of characteristic auroral phenomena for comparison with synchronous magnetic changes, or conversely; and

(iii) By selecting a few first-class displays and comparing the auroral and magnetic phenomena in detail from minute to minute.

Some notes on these three modes of treatment as applied to the Fort Rae material were communicated to the Magnetic Association of the International Union of Geodesy and Geophysics at its meeting in Edinburgh, September 1936, and will not be reproduced here. Suffice it to say that in the following discussion all three methods of analysis have been applied, but particularly the first and third; the first part of the subsequent discussion relates to the statistical treatment of auroral intensity and disturbance.

(b) *Auroral intensity and magnetic disturbance.*—For a measure of disturbance the hourly values of $Hr_H \cdot 10^{-4}$ and to a less extent $Zr_Z \cdot 10^{-4}$ have been used. In comparison with hourly magnetic character figures specifically formed for such a purpose, the hourly ranges or range products have the disadvantage of being numbers of two or more digits. And, in common with hourly characters, they necessarily fail to take account of the detailed behaviour of the field with the hour; but with the material available they provide the best numerical counterpart in magnetic disturbance to the auroral activity figures.

Corresponding with each of the groups of auroral intensity figures (0+ to 4) the mean values of $Hr_H \cdot 10^{-4}$ (to be denoted by $\overline{Hr_H}$) and the equivalent mean r_H ($\bar{r}_H$) are given in Table 105. These results make it clear that, on the broad view, the hourly range of H and therefore (as may be inferred from such inquiries as that of § 74) of Z and D increase with increase of auroral activity, and that the increase becomes rapid as the auroral intensity rises above 2. In Table 105 r_H varies approximately as the square of the intensity.

It should be noted that though $\bar{r}_H$ associated with intensity 1 is approximately the same as $\bar{r}_H$ from all hours of the year (Table 80) it is four times as great as $\bar{r}_H$ from all hours of the 38 selected quietest days (22 γ), and even in auroral hours of intensity 0+, $\bar{r}_H$ is $2\frac{1}{2}$ times as great as $\bar{r}_H$ on those q' days. From the other side $\bar{r}_H$ during hours of intensity 2 is 22% less than $\bar{r}_H$ from all hours of the 40 most disturbed days (217 γ), but 190% more than $\bar{r}_H$ from all hours of the year. Thus while the short period magnetic disturbance associated with aurora of intensity 0+, 1, and 2 is of moderate proportions on the Fort Rae scale of disturbance, the disturbance associated with intensities 3 and 4, especially with 4, is well in excess of the average of even disturbed days at that station.

TABLE 105.—MEAN $Hr_H . 10^{-4}$ ASSOCIATED WITH AURORAL INTENSITY FIGURES: ALL OCCASIONS.

Auroral Intensity.	4.	3.	2.	1.	0+.
$Hr_H . 10^{-4}$ (γ^2)	386	186	130	71	44
$\bar{r}_H$ (γ)	500	241	169	92	57

The results in Table 105 were obtained by weighting equally each occurrence of the various classes of auroral intensity—that is, the value of 386 γ^2 for Hr_H on hours of intensity 4 was derived by dividing the summarised values of $Hr_H . 10^{-4}$ on the 50 occasions of intensity 4 by 50 and so on. When the months are treated separately in a similar way the results as given in Table 106 show that the general relationship between auroral intensity and magnetic range is not invariable. In seven of the eleven months of the table $\overline{Hr_H}$ increases throughout the range of intensities, but anomalies occur in October and November 1932 and May and August

TABLE 106.—CHANGE OF $Hr_H . 10^{-4}$ WITH DECREASING AURORAL INTENSITY: MONTHS EQUALLY WEIGHTED.
(Figures in brackets are numbers of contributing hours.)

Month.	Mean $Hr_H . 10^{-4}$ associated with Auroral Intensity.				
	4.	3.	2.	1.	0+.
1932 Aug.	627·0 (6)	180·2 (28)	149·0 (39)	71·5 (20)	43·5 (10)
Sept.	336·9 (25)	162·7 (35)	79·6 (44)	61·9 (16)	23·0 (4)
Oct.	..	90·6 (7)	82·1 (35)	91·3 (22)	
Nov.	131·0 (2)	213·3 (7)	134·2 (47)	61·8 (47)	39·8 (21)
Dec.	321·5 (2)	125·4 (44)	108·7 (73)	72·7 (62)	36·5 (31)
1933 Jan.	315·0 (5)	191·9 (28)	117·0 (70)	60·7 (111)	40·7 (39)
Feb.	388·6 (7)	192·5 (33)	145·3 (62)	61·1 (77)	60·2 (27)
Mar.	630·7 (3)	195·8 (42)	136·6 (52)	75·3 (53)	19·2 (6)
Apr.	..	344·4 (16)	193·4 (56)	94·9 (32)	17·0 (1)
May	..	255·3 (3)	171·3 (10)	69·1 (11)	129·0 (3)
Aug.	..	221·9 (20)	133·2 (33)	139·9 (17)	
Mean	393·0	197·6	131·9	78·2	45·4

1933. The following paragraphs, in which all hours are G.M.T. hours unless where stated otherwise, form a summary of the results of an examination of some of those anomalies:—

(i) On November 28 the two hours ending 8h and 10h were assigned auroral intensity 4, but the simultaneous values of $Hr_H . 10^{-4}$ were only 107 γ^2 and 155 γ^2, equivalent to r_H values of 139 γ and 201 γ respectively. On the same day the hour ending 13h was of intensity 1, but had $Hr_H . 10^{-4}$ equal to 252 γ^2. Aurorally the hour ending 8h was characterised much more by a persistent and strong arc system across the north sky than by active, overhead ray-structured formations (Cn, D, and C) as is usual in "4" hours. Though not differing from many other hours to which intensity 4 was assigned, the hour ending 10h had all the really active aurora concentrated into the last 15 minutes. On the other hand, during the period 12–13h, when r_H was large, aurora was continuously weak, diffuse, and generally quiescent.

A tentative inference regarding the anomalies of these hours might therefore be that the scale of magnetic disturbance is to be related to the form of the auroral activity as well as to its brightness, and, in particular, that of two hours of equal intensity, one dominated by ray-structured aurora and the other by quiet arc forms, the hour of structured aurora will be the more magnetically disturbed. Further, it is already clear that there are unquestionable occasions when the scale of magnetic disturbance is disproportionate to the measures of simultaneous auroral activity as presently based on brightness alone.

(ii) High range associated with intensity 1 in October. The chief contributors to this anomaly were the four hours 9–10h on the 15th, 10–11h and 12–14h on the 20th, when the values of $Hr_H \cdot 10^{-4}$ were 339, 246, 271, and 320 γ^2 in succession. During the single hour to which an intensity was assigned on the 15th, aurora was probably never absent. At times the greater part of the overhead sky was filled with luminosity which was mainly diffusely structured; both rayed and homogeneous arcs were observed. It is probable that this is an example of an hour which, because of the continuity, variety, and widespread nature of the aurora, really merited a higher hourly figure, but which on the basis of intensity alone could not be rated higher than 1. The hour ending 11h on the 20th was uniformly poor in aurora; a feeble HA degenerating to a glow, and a weak RA with R movements along it, constituted the main features. The horizontal magnetic field, on the other hand, fell fairly rapidly though unsteadily in the second half of the hour. This is an example of the magnetic field, as judged by the hourly range, being more highly disturbed than might have been anticipated from the simultaneous aurora.

Later the same evening between 12h and 14h G.M.T. all three elements of the field were affected by rapid oscillatory movements, particularly Z after 13h. The aurora, however, was given no higher intensity than 1 at any of the individual observations in the hour, though the form of the activity was mainly ray-structured. Towards the end of the interval increasing twilight and cloud amount made trustworthy observation impracticable. This example of disparity between auroral activity and simultaneous magnetic disturbance, in the sense that the scale of disturbance was greater than might have been expected from the observed aurora, provides further illustration of the inference already made that the degree of magnetic disturbance is generally greater when aurora is ray-structured than when it is of the quiet homogeneous arc or glow form; it also suggests that aurora of any degree of assigned intensity occurring late in a display, *i.e.* in the early hours of the morning, is associated with a greater degree of disturbance than aurora of the same intensity occurring earlier in the evening. It is possible that this arises from the intensity being under-estimated as twilight strengthens in the morning hours, a question on which light can be thrown by considering whether, with the same degree of auroral intensity, magnetic disturbance increases progressively from early evening to early morning in mid-winter months from which twilight effects can be eliminated. This will be examined in § 116.

(iii) High range associated with intensity 0+ in May. In this month only three hours, all on the 10th, were assigned an intensity 0+. The hours with their values of $Hr_H \cdot 10^{-4}$ are 6–7h 34 γ^2, 8–9h 234 γ^2, and 9–10h 119 γ^2, and of these only the second and third are anomalous. A very active outburst of aurora about 7h 50m quickly subsided so that by 8h there was no visible activity. No further aurora was observed till 9h, when a very temporary and weak ray band formed. By that time moonlight and very strong twilight made observation difficult, but it is evident from the notes that, at least between 8h and 9h 15m, whatever aurora passed unobserved was of very low intensity. During this time, however, the magnetic field had continued in the disturbance, which started at the time of the auroral outburst immediately before 7h 50m. This must therefore be taken as a further illustration of considerable disturbance associated with little or no auroral activity in the twilight hours of the morning.

(iv) High range associated with intensity 1 in August 1933. Several of the 17 hours of intensity 1 in this month had unusually large hourly ranges for this degree of intensity; 9–10h on the 24th with 649 γ^2 for $Hr_H \cdot 10^{-4}$, equivalent to an r_H of 840 γ, is the outstanding one. The H component was recovering rapidly from a deep depression which extended over the preceding hour, during the early part of which aurora had been active but by 8h 40m had degenerated into a glow which persisted till 10h. Cloud, mainly of the high thin Ci and Cist type, veiled 8/10ths of the sky, and twilight was becoming increasingly strong, but the conditions were such that any aurora of average brightness or any noteworthy ray movements would have been observed unless they were exceptionally transitory. From this and other instances of a similar kind the inference would seem to be that secondary effects of a perturbing field associated with an active auroral outburst in one hour may spread into a subsequent hour, so that the release of the field accompanied by considerable magnetic movements may be in progress after aurora has degenerated into a quiet glow or has even disappeared. On this view the large recovery range in H during the hour 9–10h was simply a necessary sequel to the large depressing movement in the horizontal component in the preceding hour and is therefore not referable to the aurora during 9–10h. If this view is upheld it implies that such purely statistical inquiries as the present have their value seriously diminished, especially if the magnetic measures of disturbance are based on hourly ranges. It also implies that before particular perturbations in the magnetic field are referred to simultaneous auroral activity, those perturbations which are merely relaxational will require to be eliminated.

§ 116. *Variability of relationship between magnetic disturbance and aurora with time of occurrence of aurora.*—To examine whether the degree of disturbance (as

TABLE 107.—HOURLY RANGE IN HORIZONTAL FORCE ASSOCIATED WITH AURORAL INTENSITY FIGURES IN VARIOUS 3-HOURLY INTERVALS.

($\overline{Hr}_H$ in $10^4\ \gamma^2$ units: $\bar{r}_H$ in γ.)

3-Hourly Interval.		Auroral Intensity.														
		4.			3.			2.			1.			0+.		
No.	Hours G.M.T.	$\overline{Hr}_H$.	$\bar{r}_H$.	No.	$\overline{Hr}_H$.	$\bar{r}_H$.	No.	$\overline{Hr}_H$.	$\bar{r}_H$.	No.	$\overline{Hr}_H$.	$\bar{r}_H$.	No.	$\overline{Hr}_H$.	$\bar{r}_H$.	No.
1	0–3	..	..	..	131	170	15	86	111	27	42	54	29	25	32	28
2	3–6	394	511	13	178	231	49	118	153	106	35	45	88	19	25	29
3	6–9	391	506	29	198	257	139	139	180	223	70	91	126	63	82	14
4	9–12	354	459	8	183	237	53	130	169	136	87	113	142	57	74	21
5	12–15	..	..	..	166	215	6	138	179	28	94	122	78	55	71	43
6	15–18	..	..	..	..	..	..	279	362	1	140	181	4	77	100	7

measured by the hourly range or range product) associated with any class of auroral intensity varies with the time of incidence of the aurora, the hours in each of the five classes of auroral intensity 4 to 0+ were grouped according to whether they occurred in one or other of the six three-hourly periods 0–3h, 3–6h to 15–18h, and mean values of $Hr_H \cdot 10^{-4}$ ($\overline{Hr}_H$) were determined for each of the 30 groups so formed. The results along with the equivalent values of the simple hourly range ($\bar{r}_H$) are shown in Table 107.

All the hours of intensity 4 fell in the three consecutive three-hourly intervals between 3h and 12h, so that the scope for variety in closeness of association between the two phenomena is limited. The results of Table 107 indicate, however, that there is a tendency for auroral figure 4 in the earlier part of the night to be accompanied by greater range in H than in the later part. For auroral figure 3 the greatest magnetic disturbance occurs when the aurora falls in the three-hourly interval (3rd line in the first column of the table) which includes, and is almost centred at, local midnight (7h 45m G.M.T.), and the disturbance falls off towards the preceding evening and following morning. When the auroral intensity is 2 or less, the relationship according to Table 107 is more complex. The H range in the midnight interval is greater than in the two earlier intervals and, except for intensity 1, is also greater than in the two subsequent intervals, *i.e.* up to 15h. But $\bar{r}_H$ associated with any one of the intensities 2, 1, or 0+ is greater in the three-hourly period 15–18h than at any other time of the night. For hours of intensity 1 alone the range $\bar{r}_H$ increases steadily from 6–9h to 15–18h G.M.T. There is therefore a strong indication that morning aurora of weak or moderate intensity is liable to be accompanied by greater disturbance than is aurora of similar intensity occurring at any other period. Still confining attention to the same category of aurora (intensities 0+, 1, and 2), it is also clear that the ranges in intervals numbered 4 and 5 in Table 107 exceed those in 2 and 1 respectively, so that aurora of these categories which occurs at any time after midnight is generally associated with greater H ranges than aurora of the same intensity which occurs at an equal interval before midnight.

Inter alia, it is further noticeable (1) that within each of the six separate intervals into which the data of Table 106 have been divided, the range increases progressively from the class of auroral intensity 0+ to that of 4; (2) that in the interval 3–6h G.M.T. the average range associated with the 29 hours of intensity 0+ (25 γ) is insignificantly greater than the range from all hours of the 38 quietest days in the year (22 γ), but that the range for the 13 hours of intensity 4 in the same interval (511 γ) is 20·4 times greater than for the 0+ hours.

§ 117. *Distribution of* r_H *and* r_Z *magnitudes in hours of auroral intensity* 4.—In Table 105 it was shown that $\bar{r}_H$ from the 50 hours of auroral intensity 4 was 500 γ; for the same 50 hours $\bar{r}_Z$ was 427 γ. To see how these mean ranges have been made up, their frequency distribution in 100 γ intervals has been examined with results as shown in Table 108. This table confirms that a wide range of degree of disturbance may be associated with the same nominal auroral intensity; r_H in particular may be less than 200 γ or it may exceed 1200 γ, and r_Z may be less than 100 γ and greater than 900 γ. The distribution between those limits is irregular in both components, but 62% of the 50 values of r_H lie between 200 γ and 600 γ, and 64% of r_Z values lie between 300 γ and 600 γ. In comparison with this it will be recalled (Table 65) that on all days of four representative months 87% of r_H values fell below 200 γ and 95% of r_Z values fell below 300 γ.

TABLE 108.—DISTRIBUTION OF r_H AND r_Z DURING 50 HOURS OF AURORAL INTENSITY 4.

r (γ).	0–99	100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	1000–1099	1100–1199	1200–1299
r_H	..	5	7	8	9	7	4	4	..	3	2	..	1
r_Z	2	7	2	9	14	9	3	2	1	1			

If each of the range intervals 0–99 γ, 100–199 γ, 200–299 γ, and so on be denoted by a figure indicating the number of hundreds of γ in the lower limit of the interval, *e.g.* the first interval is 0, the second 1, and so on, the relation between r_H and r_Z for the 50 hours of intensity 4 can be readily summarised as in Table 109. The chief facts brought out by this table are, firstly, that low and high values of r_Z are in general associated with correspondingly low and high values of r_H, and, secondly, that in 44 of the 50 hours the value of r_H falls in an interval as high as or higher than the interval for the corresponding value of r_Z. The remaining six occasions on which r_Z exceeded r_H occurred at the following times:—

Date.	Hour.	r_H.	r_Z.
	G.M.T.	γ	γ
1932 September 19	8–9	290	470
26	6–7	344	556
27	6–7	382	639
27	7–8	364	499
1933 February 23	7–8	728	806
27	6–7	432	594

Generally the lower r_H value arose from the horizontal component oscillating rapidly without any dominant movement in the direction of increase or decrease of the field, while Z at the same time was undergoing persistent disturbance in one direction.

TABLE 109.—RELATION BETWEEN r_H AND r_Z IN HOURS OF AURORAL INTENSITY 4.

r_Z Interval Number.	r_H Interval Number.												
	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
0	..	2											
1	..	..	3	4									
2	..	..	1	1									
3	..	..	1	4	1	2	1						
4	..	..	1	1	7	3	2						
5	..	..	..	1	1	2	..	2	..	2	1		
6	..	..	..	1	..	..	1	1					
7	..	..	..	..	..	..	..	..	..	1	1		
8	..	..	..	..	..	..	..	1					
9	..	..	..	..	..	..	..	..	..	..	..	..	1

§ 118. *Magnetic disturbance during absence of aurora.*—From the detailed auroral notes those dates and times were listed when sky conditions were suitable for the observation of aurora, but when in fact no, or only very poor, aurora was noted. On many such occasions the absence of aurora lasted for only a fraction of a whole Greenwich hour, so that hourly ranges, as already measured and used, could not be applied to characterise simultaneous magnetic disturbance. Such broken hours were omitted and a further list made showing only the Greenwich whole hours of poor or no aurora. When the first note of aurora appeared at a time in the evening two or more hours after conditions of twilight had become favourable (other conditions being also favourable), the estimated starting-time for possible aurora was based on the distribution of hours of aurora in the appropriate month as shown, *e.g.* by Table 95; in such a month as March the starting-time was taken as 2h G.M.T. in the first half of the month and 3h in the second half. Finally, the values of $Hr_H \cdot 10^{-4}$ for each of the hours so listed were entered in a schedule which gave the net results shown in the accompanying Table 110.

$\bar{r}_H$ for all 193 hours of no or poor aurora was 23 γ, or only 1 γ more than for all hours of the 38 days selected as being magnetically quietest during the whole 13 months. Conditions in the magnetic field simultaneous with absence of aurora are therefore approximately equivalent to the average of the quietest of all days; or, stated otherwise, magnetic disturbance of any appreciable magnitude is unlikely to occur in the absence of aurora.

It will be recalled from Table 105 that the average r_H associated with hours of auroral intensity 0+ was 57 γ and for intensity 1, 92 γ. It is therefore clear from Table 110 that, though the increase of scale of disturbance is relatively slow up to auroral intensity 1, the change from complete absence of aurora to just perceptible aurora (0+) is significant in its effect on the magnetic field, the range in H being increased $2\frac{1}{2}$ times.

TABLE 110.—HORIZONTAL FORCE RANGE IN HOURS OF NO AURORA.

Hour G.M.T.	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	Total (or Mean).
Total number of no aurora hours	12	17	22	27	23	21	11	10	4	4	6	11	13	9	3	193
Average $Hr_H . 10^{-4}$ (γ^2)	13	17	14	15	18	13	10	12	7	35	22	40	23	41	10	18
Equivalent r_H. (γ)	17	22	18	19	23	17	13	16	9	45	28	52	30	53	13	23
Group mean $Hr_H . 10^{-4}$ (γ^2)					14							31				
Equivalent r_H (γ)					18							40				

A further feature of interest in Table 110 is the difference in the hourly ranges in H between the two groups of hours before and after 9h G.M.T. In the earlier part of the evening, which normally includes the maximum of the diurnal variation of irregular disturbance of short period, there were 147 hours of no aurora; $\bar{r}_H$ for these hours was only 18 γ. For the 46 hours of no aurora after 9h, $\bar{r}_H$ was 40 γ, and, as the table shows, the individual hourly means of r_H from 9h to 14h were all higher than any one of the nine hours before 9h. In detail, 5 hours of the 147 before 9h had values of Hr_H above 50 γ^2 (*i.e.* $r_H = 65\ \gamma$) with the greatest 87 γ^2 ($r_H = 113\ \gamma$), but in the 46 hours after 9h, Hr_H exceeded 50 γ^2 in 6 hours with the three greatest values of 133, 124, and 123 γ^2, or in terms of r_H, 172, 161, and 160 γ. It would therefore seem that whatever slight disturbance does occur in the absence of aurora, it is more likely to occur in the early morning than in the late evening hours. One of the difficulties in the way of making such an inference rigorous arises from certain features in the technique of auroral observing as practised at Fort Rae. As soon as the presence of aurora was detected, observations were made at intervals of five minutes or less, but until aurora was first observed each evening, or after a display had apparently stopped, the interval was extended to 15 minutes. It is therefore possible that a sudden flare-up and disappearance of some short-lived auroral form could pass unnoticed, especially in the latter part of a night's display. For it was noted as a characteristic of aurora at Fort Rae, that morning aurora, particularly in its appearance just before twilight, was liable to be more fleeting and sporadic than in the early or middle hours of a display.

§ 119. *Disturbance during overhead aurora.*—A cursory examination of the magnetograms at the time of strong and active aurora, especially when of the drapery type and when in the overhead sky, showed that many of the quickest perturbations in the magnetic field occurred simultaneously with this type of aurora. The simplest way of demonstrating such a relationship is to identify the most active periods of overhead aurora with the formation of coronas, and to list the ranges in H and Z for the hours within which coronas have been observed to occur. Table 111 summarises the results derived from such a list and is based on the appearance of one or more corona forms in each of 48 hours during displays in August and September 1932.

$\bar{r}_H$ from all 48 hours is 420 γ and $\bar{r}_Z$ 351 γ. $\bar{r}_H$ for these corona hours is therefore 80 γ and $\bar{r}_Z$ 76 γ less than their corresponding values derived from the 50 hours of auroral intensity 4. This reduction is not surprising, for the corona hours varied in intensity from 1 to 4, being made up of 20 4's, 22 3's, 5 2's, and one hour (of very weak corona and little other activity) of intensity 1, giving an average of 3·3. So that the reduction in range from hours of intensity 4 to corona hours is approximately proportional to the reduction in average intensity.

TABLE 111.—HORIZONTAL AND VERTICAL FORCE RANGES IN HOURS WHEN CORONAS WERE OBSERVED.

Hour G.M.T.	4	5	6	7	8	9	10	11	Total or Mean.
No. of Corona hours	1	5	8	14	10	9	1		48
Average $Hr_H . 10^{-4}$ (γ^2)	400	427	251	357	345	260	233		324
Equivalent r_H (γ)	518	554	325	463	447	337	302		420
Average $Zr_Z . 10^{-4}$ (γ^2)	3701	2828	1703	2068	2300	1598	1743		2100
Equivalent r_Z (γ)	619	473	285	346	384	267	291		351
Average $Hr_H . 10^{-4}$ (γ^2) all days	79	120	170	195	183	144	91		140 ($r_H = 182\ \gamma$)
,, ,, ,, 10 d' days	134	311	397	437	484	358	161		326 ($r_H = 423\ \gamma$)

A more surprising feature is the constancy of the ratio $\bar{r}_Z/\bar{r}_H$, the value of which (0·84) is almost identical for both groups of hours and is also practically the same as for all hours of the year (0·87). Though admittedly only in a very approximate way, the value of this ratio may be regarded as an indication of the relative magnitudes of the two meridian force component vectors in the perturbing field, and therefore of the average direction of orientation relative to the station of the disturbing current system which produces the perturbations. Now it might have been supposed that the appearance of aurora of such brightness as called for assignment of an hourly intensity 4, and aurora of corona form, would have effected a distribution of the disturbing current system different from that obtaining on the average of all hours. The constancy of the ratio $\bar{r}_Z/\bar{r}_H$, however, suggests that whatever change is effected in the magnitude of the disturbing field, its direction of orientation and elevation relative to the station remains practically constant through all grades of auroral intensity and all positions in the sky. The inference would therefore seem to be that aurora is really only an indication that other conditions in the high atmosphere more dominant over the surface magnetic field have been greatly intensified and that the aurora *per se* has little direct effect on the field. Alternatively, if the short period perturbations measured by the hourly range are primarily to be related to earth currents, then however much these may vary in strength and direction of flow, they must maintain a rough constancy of orientation and position relative to the station whether the aurora be high or low in the sky.

In addition to showing the separate magnitudes of r_H and r_Z during corona hours, Table 111 indicates that more than 50% of those hours in August and September fell between 7h and 9h, and 85% between 6h and 10h. The times of appearance of coronas are therefore very strongly concentrated in a few hours around local midnight. Now the diurnal variation of irregular disturbance normally has a maximum in those same hours irrespective of their auroral character, and, in particular, $\bar{r}_H$ for the seven hours 4h to 11h covered by Table 111, but derived from all 61 days of August and September 1932, was 182 γ. By comparison with the value of 420 γ for the 48 corona hours this indicates that the presence of coronas intensifies irregular disturbance more than twofold even in these disturbed hours. On the other hand, $\bar{r}_H$ for the same seven-hourly interval on the ten of the 40 selected most disturbed d' days which occurred in August and September was 423 γ, which confirms a deduction of an earlier section that corona hours are not necessarily the most magnetically disturbed hours. If the difference to be accounted for had been larger, the explanation might have been found in the likelihood that some of the most brilliant coronas passed unobserved on cloudy nights.

Detailed examination of the hours in the schedule of which Table 111 is a summary has further confirmed that, though an hour of corona very frequently coincides with the hour of outstanding r_H in a day or group of days, instances of the hour of greatest r_H preceding, or more usually succeeding, the corona hour are not uncommon.

A typical example of the coincidence of coronas and large r_H values occurred on August 27. For the four hours starting 6h, r_H was 216 γ, 879 γ, 1094 γ, and 213 γ, and of these the second and third were the corona hours. For the four hours starting 4h on September 25, on the other hand, r_H was 101 γ, 476 γ, 487 γ, and 925 γ, and specific mention of appearance of a corona was made only in the second and third of these hours. During the fourth hour, however, the aurora consisted of brilliantly coloured active draperies. There are other instances in which the range in the corona hour may be as low as 60 γ, though in such instances the range in neighbouring hours also is likely to be small.

In considering the relationship between overhead auroral activity and concomitant magnetic disturbance it is well to keep the following features in mind. Corona forms vary widely in their colour and brightness and in the length, sharpness, and liveliness of movement of their constituent rays. A corona may form from a convergence of intensely luminous and highly coloured long-rayed draperies in violent undulatory and rotary movement, or it may form quietly from a drapery which has been active and bright but is rapidly weakening and becoming diffuse. A corona of the first type will be characterised unhesitatingly as of intensity 4, but 1 may be the maximum intensity permissible for the second type.

Further, though the formation of a corona is the usual climax to a period of great overhead activity it is not invariably so. Recurrent surges of strong curtains and draperies may form in the middle sky and mount towards the zenith, but without their rays sufficiently encircling the zenith to produce the corona effect, or the corona may be so transient (one second or less) that its formation has escaped observation. The accident of activity of this kind being deficient in the final—and, from the magnetic viewpoint, perhaps relatively unimportant—phase of complete encirclement of the zenith necessitates that such hours be excluded from an examination of which Table 111 is a summary, but the simultaneous magnetic effects are frequently very great compared with those of indifferent corona. All the low r_H values in corona hours in August and September have been found to occur when the corona was weak and diffuse and had not been preceded by any very active draperies, while the occurrences of large r_H in hours adjacent to corona formation were associated with brilliant draperies in the overhead sky, but which did not culminate in coronas.

§ 120. *Summary of broad relationships between aurora and magnetic disturbance.*—Before proceeding to examine some detailed features of the relationship between auroral activity and simultaneous magnetic disturbance it is desirable to collect and summarise the deductions made from the statistical survey in preceding sections. In this summary it will be understood that, unless otherwise mentioned, the measure of magnetic disturbance is the hourly range (r) in H or Z, that the times are G.M.T., and that the auroral intensities are as defined in § 107 for 60-minute intervals beginning at the exact G.M.T. hour.

(*a*) The degree of disturbance increases with auroral intensity, the increase being more pronounced as the intensity increases above average.

(*b*) Breakdown of the general relationship (*a*) can usually be traced to the fact that the assignment of auroral intensities, according to the recommendations laid down in the *Atlas of Auroral Forms*, published by the International Geodetic and Geophysical Union, gives undue weight to the mere brightness of the aurora. A quickly moving ray-structured aurora, whether of RA, Cn, D, or C form, will have associated with it a greater degree of disturbance than a quiet form of similar intensity.

(*c*) All instances of a disproportion between the scale of disturbance and simultaneous aurora are not explicable in terms of (*b*). Occasions of considerable disturbance associated with poor auroral intensity are more common than the converse.

(*d*) The degree of magnetic disturbance coincident with morning aurora is likely to be greater than with aurora of the same intensity appearing before midnight. This is particularly true of the weaker intensities.

(*e*) There are indications that in some hours of negligible aurora the changes in the magnetic field are to be regarded as movements towards recovery to a normal value following large unidirectional perturbations in a preceding hour in which auroral activity was strong.

(*f*) In hours of greatest auroral intensity the magnetic disturbance in H may be 20 times as great as in hours when no aurora was observed but when conditions were favourable for observing it. The degree of disturbance in hours of the latter category is less than half that associated with just perceptible aurora.

(*g*) The ratio of disturbance ranges in the two meridian components H and Z is the same for all days as for selected hours in which coronas were observed and for hours of maximum auroral intensity. With qualifications this is considered to indicate that the distribution of the disturbance field is little affected by aurora whatever its intensity or position in the sky.

(*h*) Though generally associated with the most active phases of an auroral display, coronas are not invariably accompanied by the greatest magnetic disturbance. Strong draperies and curtain activity which have not culminated in corona formation are accompanied by greater disturbance than weak and diffuse coronas.

§ 121. *Auroral activity and magnetic disturbance: procedure in more detailed examination.*—In §§ 114–119 the results have been given of an examination of some of the broader relationships between auroral intensity and simultaneous magnetic disturbance at Fort Rae. Owing to the nature of the available measures of auroral activity on the one hand and of disturbance on the other, that examination could be considered only as a somewhat crude first approximation to a more detailed inquiry. As a second approximation, the plan adopted has been to dispense with ready-made measures referring to rigidly fixed time intervals and to compare in respect of their times of incidence and approximate magnitudes some of the more noteworthy magnetic perturbations in a limited number of days with simultaneous auroral events as described in detail in the auroral log books. In general, the detailed comparison and analysis has been extended as far as the nature of the auroral activity would allow, but it will be understood that it was exceptional for the phenomena to be so simple that any one phase of magnetic disturbance could be associated uniquely with one auroral form. Much more usually, two or more types of aurora co-existed with different intensities, areas of sky covered, positions, colouration, and movement, so that it was impossible to decide which particular aspect of the aurora ought to be related to the simultaneous field changes. In this connection it is well to state here, as one of the secondary results of this inquiry, that similar examinations would probably be more profitable if made using the data for a station somewhat farther removed from the zone of maximum frequency of aurora. For at such a station both the auroral and the magnetic disturbance data would be simpler, so that whatever relationships between the two phenomena exist might be expected to become evident more readily.

In detail the procedure which has given rise to the following notes has been first to select and summarise the main features of a number of auroral displays and then to refer these to simultaneous magnetic field changes, particularly in the meridian force components H and Z. Where these latter have been of a form suitable for estimating displacement from a normal value at the time, the field vector has been referred to an atmospheric disturbing current system supposed linear and simple.

The values given for the changes of field are to be considered as approximate; they are intended to represent the order of the changes involved rather than their accurate magnitude. When the aurora is described as coloured, colour other than the usual greenish yellow is meant. It is usually red, crimson, or purple, or, as specially mentioned on one or two occasions, a particularly emerald quality of green without the yellow of the normal aurora. The notes cover the period of one month from 1932 August 17.

§ 122. *Analysis of, and comments on, auroral and magnetic events on a number of consecutive evenings.* 1932 *August* 17.—Both phenomena were relatively simple. From 8h to 9h and from 9h 29m to 10h aurora was of not more than moderate intensity and mainly in the south sky. Between 9h 03m and 9h 19m and again from 9h 25m to 9h 28m it was both very active in ray-structured formations and highly coloured; in these short intervals the activity was widespread over the sky, though chiefly concentrated overhead. At 9h 15m the aurora was observed to migrate from the southern to the northern side of the magnetic prime vertical plane.

In the same part of the night the features of the magnetic field were a triangular bay in H and a double oscillation in Z coincident with the appearance of the greatest auroral activity. There was no highly oscillatory disturbance such as might have been expected to form the magnetic counterpart of the auroral outburst in the first quarter-hour after 9h. Instead, H was depressed through 206 γ at a relatively slow rate and with only slight irregularities; it recovered again in a similar way as if a perturbing field had been steadily superposed from 9h 03m to 9h 18m, and then had been gradually withdrawn so that the main field was approximately normal by 9h 40m. In this same time Z rose 100 γ from 9h 02m to 9h 10m, fell 200 γ to 9h 18m, rose to its 9h 10m level at 9h 23m, and then diminished to normal by 9h 40m. From the behaviour of these two meridian force components of the perturbing field we might therefore deduce that the disturbance current system lay to the south of the station till 9h 10m, crossed to north, and remained there till 9h 23m, and subsequently returned to south of the station again; the current direction was from east to west up to 9h 18m and in the reverse direction thereafter.

From these notes it is to be inferred that though broad features of similarity in the course of the two phenomena are discernible they are almost concealed by differences in detail. The time of start of the main perturbations in H and Z agrees with the beginning of the first active phase of the auroral display, and the end of this phase approximately coincides with the change in direction of the field movements. But against these there is the difference in time between migration of the auroral activity from the south to north sky on the one hand and the disturbance current on the other. During the time (9h 04m to 9h 18m) of most intense and active current movements in the overhead sky, the H and Z components showed no sign of rapid oscillation. Waves in curtain formations progressed from west to east, while the disturbance currents, if above ground, were directed from east to west. And, more generally, the scale of the magnetic field perturbations (200 γ) when compared with others frequently registered in both H and Z were disproportionate to the brilliance of the auroral activity.

The impression is left that the aurora is only a manifestation that other phenomena—to which the aurora is only loosely related—more directly associated with the changes in the field are in progress at the same time.

1932 *August* 18.—As on the previous night, the auroral activity was mainly concentrated into two brief intervals, 8h 52–55m and 9h 08–15m, the second of which, it may be noted, coincided with a similarly very active interval on the 17th. But even in the early part of the display from 6h 25m to 8h 50m there were short periods of strong intensity with much wave movement. Following the second very active interval, which ended at 9h 15m, aurora rapidly degenerated except for a momentary curtain formation at 9h 19m.

The changes in magnetic field during this display were even less conspicuous than on the preceding evening. Up to 8h 50m both H and Z showed only very slight irregularities. At 8h 52m, when a brilliant corona appeared, H stopped falling in a very small irregular slow movement, and in the next three minutes during violent curtain activity there was a steady rise of only 35 γ, which is a quite insignificant change on Fort Rae standards of disturbance. Between 9h 08m and 9h 19m, when aurora took the form of overhead curtains with rapid wave movement and strong colouration with occasional tendency to corona formation, H was undergoing a second sluggish diminution terminating in some slight oscillations of 10–20 γ range. Coincident with this the vertical field fell sharply in a single oscillation culminating at 9h 12m, followed by a slow rise to 9h 19m. At the same time (9h 12m) as Z reached its minimum value the overhead curtains were observed to migrate into the north sky. On the other hand, if the perturbations in H and Z are to be related to a current system above ground level, the direction and times of changes in these components require that at 9h 12m an EW. directed current passed from north to south of the station.

The conclusion from this analysis must therefore be very similar to that for August 17, viz. that while some broad features in the two phenomena correspond, there is little close relationship in detail. In comparison with other instances of magnetic disturbance simultaneous with aurora, the disturbance of the 18th, even more than on the 17th, was wholly out of proportion to the intensity and activity of the aurora in some brief intervals, and, in particular, the direction of movement of the aurora was opposite to that deduced from the magnetic field on the basis of an elevated current system.

1932 *August* 19.—Both aurorally and magnetically the activity on this evening was slight. While an arc system remained quiet until 6h 27m, the field was very steady without clear suggestion even of displacement from its mean position. At 6h 27m, when the arc became active as a ray band, both H and Z were affected by a few small damped oscillations of 20 γ amplitude, which rapidly diminished to 3 or 4 γ. Later (at 6h 54m), when curtains with traversing waves moved into the south sky, the force components showed only two or three small waves of 20–25 γ amplitude, and at 6h 57m when an arc suddenly strengthened to intensity 3 only small irregularities were noticeable.

Hence, neither when the aurora was obviously quiet nor when it was temporarily strong and active was the magnetic field affected by other than small movements. The only significant correspondence in behaviour occurred when an HA disintegrated into broken ray bands; oscillations were then set up in both H and Z after a quiet period.

1932 *August* 20.—On this evening aurora was intermittently present from 5h 13m to 10h 20m. Up to 7h 57m it was chiefly in the form of weak and quiet arc formations in the overhead sky though R structure with spasmodic intensification (*e.g.* at 6h 27m) was observed. During the whole of this period, lasting $2\frac{3}{4}$ hours, the magnetic field was completely quiet. At 7h 57m brightly coloured curtains with much movement appeared temporarily, but still with no magnetic counterpart. In the five minutes following 8h 07m a corona rapidly developed from RB and draperies. Just before the formation of the corona at 8h 10m H fell rapidly through 120 γ and Z rose 60 γ, but with the completion of the corona these movements were instantaneously reversed. From 8h 13m to 9h 00m intermittently bright and frequently brilliantly coloured curtains formed with very quick movements, mainly WE. Coincident with the strongest of the auroral outbursts in this period (*e.g.* at 8h 32–35m), both force components were affected by irregular sharp movements (50–100 γ), but during intervening periods, *e.g.* 8h 18–32m, when the presence of rayed structure was noted, the field changes were smooth and regular. From 8h 40m to 44m both H and Z increased rapidly (100–150 γ), while bright curtains were rapidly lowering elevation into the south sky. The corresponding auroral and magnetic movements at this stage are roughly consistent with the hypothesis of the main disturbing current residing in the curtain, provided the current is directed from E. to W.

It may therefore be inferred that at the times of corona formation sudden sharp changes occurred in all elements, but in comparison with many other disturbances the magnetic movements were quite small even at times of auroral intensity 3. The aurora was very largely in the overhead sky, so that large departures of Z from normal were not to be expected; and when the aurora was farthest from overhead it was chiefly in the south sky, so that if the EW. disturbance currents are in some way associated with the aurora all H changes should have been below normal, as indeed they were. During the early part of the display (before 8h 00m) an arc system, which may have been an HA or very diffusely structured RA, intensified to 2 and moved bodily (6h 15m) with no significant magnetic effects, nor were there any at 6h 27m when wave movements from E. to W. progressed along an RA; even at 7h 58m, when very brightly coloured and quickly moving curtains were present, the magnetic effects were negligible.

1932 *August* 21.—A feature of this display in its early stages was a persistent quiet HA in the south sky, 7–8° above the horizon. At the same time (5–7h) the H component was irregularly depressed below its mean value and Z was increased. These changes in the magnetic field are consistent with a disturbance current system to the south if the direction of current was from E. to W. To see how far the elevation of the HA as observed agrees with what might have been deduced from the disturbance vectors in the field, it is necessary to assume values for the undisturbed value of the field, so as to assign values to the departures ΔH and ΔZ. According to the view taken of what constitutes the undisturbed field, elevations deduced from $\tan^{-1}\Delta H/\Delta Z$ ranged from 32° below the horizontal at the station to 23° above it, the latter estimate being some 15° above the HA. This value of 23° was derived by measuring the departures from the August quiet-day hourly values for the same part of the day, whereas for the first value the corresponding disturbed day values were used. That even the quiet-day normals give an elevation greater than might have been expected may be attributed to ignoring the induced currents in the earth, since these should always have the effect of reducing the Z and increasing the H vector components.

The uncertainties in relating any magnetic disturbance to a specific auroral feature reside not only in the selection of the normal undisturbed value and the presently unknown contribution from earth current effects; there is the further source of uncertainty arising from the presence in the sky of more than one auroral form. To establish such numerical relations as outlined above, an hourly interval is as short as may satisfactorily be used unless the displacements in both components of the field are unusually clear-cut, but at least at Fort Rae one auroral feature was seldom alone for an equivalent time. An HA persisted throughout the period 5–7h on August 21 which has just been examined, but at times a great part of the sky was also covered with active curtain effects.

Other features of interest in the auroral display and magnetic disturbance on the same night were, firstly, the coincidence in time between the most active aurora and the major magnetic movements (6h 38m–7h 01m); secondly, the sudden changes in the field at 6h 49m and 6h 55m occurring simultaneously with the formation of coronas; and thirdly, the reversal of wave direction in the curtain at 5h 30m from WE. to EW. coinciding with a rapid change in direction of H movement. At the same time it must again be mentioned that even the greatest of the disturbance movements during the auroral display were quite small. The large irregular depression in H and increase in Z from 12h to 17h G.M.T., when daylight was too strong for any aurora to be observed, was much greater than any movement during the aurora of the previous night. Nor is there any clear characteristic difference in the form of the movements at those two times of day. The perturbations which occur in the hours adjacent to midnight are, in general, more abrupt and intense than those of the morning and forenoon hours, but these features are not invariable.

1932 *August* 22.—Magnetic disturbance on this day illustrates the contention of the preceding paragraph. Aurora was observed from 6h 50m to 9h 37m during which time there were three intervals of very strong activity, viz. 8h 01–10m, 8h 32–35m, and 8h 50–55m. In all of these the intensity of the aurora was at least 3; it was also brilliantly coloured and in violent movement. But throughout the whole night period from 6h to 10h magnetic disturbances did not entail a departure of more than 100 γ from normal, and this only in a comparatively slow movement from 7h 59m to 8h 13m. In contrast with this all three components were almost continuously disturbed throughout the daylight hours from 11h 30m G.M.T. onwards, and at least in one phase (11h 50–56m) the field change in individual movements in Z were as rapid—200 γ in 6 minutes—as in the night-time disturbance.

Of the three intervals of strongest auroral activity in the display the first and last synchronised with small magnetic disturbance, the directions of meridian field vectors in both instances pointing to a current system in the south sky. In both, the field displacements were sufficiently clear-cut to allow measurement to be made from an undisplaced position of the record, and the deduced current elevations were 41° between 7h 59m and 8h 13m and 36° at 8h 50m. At the earlier of these times a curtain lay mainly along the magnetic prime vertical plane through Aquila, which is in agreement both with the elevation from the H and Z displacements and with the small recorded effect on the east-west component; at 8h 50m the curtain lay through Pegasus in the south sky, which again agrees roughly with the computed elevation.

It therefore seems that on occasions of dominant and isolated auroral features a fair degree of correspondence between the auroral position and the disturbing current can be found, but why the induced current appears to play so little part in these instances is not known.

1932 *August* 23.—In the early part of this display, from 5h 00m to 5h 25m, auroral activity was confined to the southern half of the sky, and in particular an HA persisted through δ Herculis whose elevation at that time was about 60° above the SW. horizon. At the same time H was decreasing and Z increasing steadily, the relative displacements being of such a magnitude as to be referable to an atmospheric current system 62° above the horizontal southward of Fort Rae. This is a further example of approximate agreement between the position of the dominant auroral feature and the elevation of the disturbing current deduced from the simultaneous magnetic field vectors.

Within an interval of approximately one half-minute (5h $40\frac{1}{2}$–41m) H fell 490 γ and Z increased almost equally rapidly. At the same time a very brilliant curtain mounted into the overhead sky. At 5h 42m, when the same curtain moved into the north sky and continued with much colouration and ray movement, the direction of the meridian H vector abruptly changed from decreasing to increasing field and Z fell very rapidly. This is a clear illustration of synchronisation of auroral activity and sharp magnetic disturbance of considerable magnitude. Later (at 5h 55m) the direction of change of the Z field reversed suddenly on the formation of a brilliant RB or curtain at a high elevation.

In the subsequent part of the display and certainly up to 8h 40m almost all the auroral activity was confined to that part of the sky northward of the magnetic prime vertical plane though much of it was very nearly overhead. Over the same time the mean values of H and Z were both below normal, so indicating a disturbance current north of the station, and, though intermittently W. to E., was dominantly directed from E. to W.

1932 *August* 24.—For at least $2\frac{1}{4}$ hours beginning 6h 08m the principal auroral feature was a persistent multiple overhead arc system, which spasmodically moved to-and-fro from N. to S. transverse to its own length. Whether the arc was a fibrous homogeneous arc or a diffusely structured rayed arc or a curtain seen from below could not be determined; at times it showed definite R structure, at other times it degenerated to have the appearance of a vague luminous "smoke-drift" through the zenith. Occasionally, as at 7h 17m when it was of intensity 3, the arc was very bright; for the greater part of its life its intensity was only moderate. But throughout this whole period, and indeed extending to 5h 13m at the beginning and 9h 40m at the end of the display, the magnetic field was completely free of any noteworthy disturbance, either in the form of steady displacement or sharp oscillations. Slow irregularities of about 10 γ amplitude were the only noticeable counterparts in any of the components.

1932 *August* 25.—Although aurora was almost continuously observed from 4h 35m G.M.T. to 10h 15m the interval of greatest concentration of activity was from 6h 48m to 7h 09m when much violent curtain activity with red colouration was in progress in the overhead sky. In this same period all components of the magnetic field were subject to very abrupt and large changes, Z about its mean value, and H well below its mean, thus indicating large fluctuations in a current system in the middle south sky and with the current flow from E. to W. Between 7h 01m and 7h 08m, when the auroral intensity was at its maximum, H fell 330 γ and Z 520 γ. Though such rapid and large changes occasionally occur in the daylight hours, they unquestionably occur more frequently in the auroral hours, and come to be considered as typical of the movements associated with very strong aurora, especially of the curtain, drapery, and corona variety. At least in H, however, the very sudden movements were only the culmination of a more protracted perturbation which had begun about 6h 48m and continued till 7h 36m. From the earlier of these times H had decreased irregularly from its normal value till 7h 10–12m when it was about 550 γ below normal, then returned approximately to normal at 7h 36m. At the time of the first part of this triangular H depression, Z had increased rapidly, but in subsequent stages Z was characterised more by large irregular fluctuations than by a steady or only moderately variable displacement from a mean value as in H.

Comparison of these magnetic and auroral phenomena leaves a strong impression that the magnetic field vectors were changing, not in rigorous relation to the observed aurora, but in association with some other highly variable and complex current system of whose presence the aurora was only one manifestation. The aurora observed from 6h 48m to 7h 00m and from 7h 12m to 36m in particular was apparently entirely secondary to, and had hardly any correlation with, this current system. If this view is substantiated, the difficulty is increased of inquiring into the real nature of the differences between apparently similar auroras which are on some occasions associated with violent magnetic disturbances and on others with almost quiet conditions.

1932 *August* 26.—The early stages of this display illustrate further the remarks of the preceding paragraph. Between 5h 48m and 6h 06m, after an hour's indifferent or moderate activity, the aurora became both active and bright, particularly in the two brief periods 5h 48–52m and 5h 58m–6h 06m. In these two periods, coronas, real or potential, formed at least four times; the intensity of the curtain and drapery formations was at times just short of the highest in the scale. Notwithstanding, none of the magnetic components was affected by disturbance movements exceeding 60 or 70 γ and the field changes were quite slow and insignificant.

Later (at 7h 06m, 7h 48m, and 8h 03–15m), when a multiple RA or curtain system stretched across the sky from E. to W. horizon and was intermittently very intense, the greatest magnetic disturbance in any one movement was only 160 γ in eight minutes in Z (8h 02–10m). Hence, though what disturbance took place on this night agreed in time with the maximum phases of the auroral display, in comparison with similar displays the magnitude of the field changes was wholly disproportionate particularly during the formation of coronas.

1932 *August* 27.—In several important features the relationship between aurora and synchronous field changes during this display was completely different from that of the previous evening. Though persistent cloud veiled some of the detailed structure of the aurora it was clear that much of the display was characterised by vigour of movement, strong intensity of illumination, and at times brilliant colouration. These characteristics were specially pronounced in the 60-minute interval from 7h 56m. Within the interval 7h 58m–8h 01m when three very bright coronas were observed, H fell 840 γ, and in the subsequent three minutes (8h 07–10m), when further coronas with strong curtain activity and much rotary movement of draperies was in progress, extremely rapid oscillations of over 300 γ range were recorded in both force components. Later in the same hour (8h 47–50m) a fresh outburst of very strong aurora including coronas was associated with a quick oscillation in both H and Z, the latter component rising through 345 γ in three minutes.

From this summary comparison it is to be concluded that on this occasion extremely rapid magnetic perturbations of the order of several hundred gammas took place synchronously (as near as can be judged) with vigorous, structured aurora. These perturbations formed part of a typical N disturbance in which, for nearly an hour, H was depressed below its normal value at this time by about 550 γ, and Z was highly oscillatory partly above and partly below its mean, so that the disturbance is to be related to a dominantly EW. current system situated mainly overhead. The auroral counterpart during the same time was widely distributed throughout the sky, though also mainly overhead in its more active periods; but in contrast to the major direction of the current, the auroral wave and ray movements were indiscriminately in both directions and even completely rotary at the strongest phases.

In comparison with the relationship between aurora and disturbance on the previous evening, that of the 27th August was both closer and more proportionate. The aurora on the 27th was consistently stronger than on the 26th, but in short periods the difference was not so great as to lead to the expectancy of such great differences in the scale of the disturbance concomitants.

1932 *August* 28.—As on the 27th, aurora on the 28th was at times intensely strong with violent motion and brilliant colouration, particularly at the times 5h 35m–6h 02m, 7h 03m, 7h 11–16m, and from 8h 32m–9h 02m. Coincident with these times some extremely sharp and large scale magnetic disturbance was recorded. Even before the most active phase in the first of these intervals had begun, H had decreased by 250 γ (5h 32–40m), but between 5h 40m and 5h 56½m the same component had fallen a further 1000 γ despite several sharp return movements of 200–250 γ range. In this same interval Z was even more highly disturbed than H, a to-and-fro oscillation of 950 γ range taking place within a very few minutes after 5h 50m. About this time overhead curtain and drapery activity in very violent motion was in progress, culminating in several transient but strong coronas. This is a further clear illustration of the most spectacular magnetic field changes (N type disturbance) coinciding with strong, structured aurora overhead. For at least 20 minutes, centred at 6h 00m, H remained depressed 850 γ below normal, while the force changes in the vertical component were both above and below the mean.

The magnetic field had not recovered from this disturbance when, at 7h 11m, a second wave of strong auroral activity began and lasted till 7h 16m. In this interval a strong rayed arc round the middle sky developed into a drapery which in turn converged in the zenith to form a corona at 7h 14m. The effect on the field of this outbreak was very small in both H and Z, but on the dissipation of the corona, Z began to fall rapidly through 450 γ to 7h 19m, by which time the sky was covered with a diffusely ray-structured luminosity. At 7h 20m a border formed on the luminosity across the NW. sky and slowly swept towards the SE., leaving the sky clear to the north. At the time of formation of this border, Z suddenly reversed its direction of change, and increased to about normal through 500 γ in seven or eight minutes.

A third very active auroral interval began at 7h 43m and lasted intermittently till 9h 09m. This period was characterised by intermittent waves of curtain activity at times strongly coloured and in violent movement, culminating in coronas which, however, were not always complete. Each fresh wave of activity in this period quickly subsided. In complete contrast to the earlier outbursts, the magnetic field, though disturbed, showed none of the spectacular characteristics of the earlier evening. Between 7h 42m and 8h 19m at least seven complete or partial coronas were noted, but in this interval the range of the greatest movements in H and Z hardly exceeded 200 γ and they were not in any way distinguished by their sharpness.

From 8h 32m to 9h 02m another period of continuously strong aurora was accompanied by very large magnetic field changes, H being again depressed in another N-type disturbance and with Z highly oscillatory well above its mean, so indicating a current system to the south of the station and directed EW. One of the surprising features of this disturbance was that, though the major downward movements took place simultaneously with the strongest aurora in this period, the time of maximum depression in H (9h 16½m) occurred about 15 minutes after the greatest auroral activity had subsided, and the recovery through 1225 γ in the 25 minutes following 9h 17m was accompanied by only moderately intense RA and RB formations.

From the viewpoint of the magnitude of occasional magnetic disturbance at Fort Rae it is worth recording that in this disturbance H was steadily below its normal value by about 1500 γ from about 9h 10m to 9h 20m, and for 20 minutes was 1100 γ below normal.

In this display there have therefore been several further unquestionable illustrations of very great field changes taking place simultaneously with maximum phases of auroral activity, but these great changes have been only the initial stages of magnetic perturbations of longer period in the succeeding stages of which the corresponding auroral activity has been reduced to moderate or lower intensity. It is also clear that in each of the two major perturbations of this type the H field was depressed, while Z was oscillatory about normal in the earlier and definitely above normal in the later perturbation, although in both cases the aurora showed no certain change in mean position as between the two outbursts. During both perturbations the greatest concentration of activity was in the overhead sky. These observations reinforce inferences already made, to the effect that while the phenomena of aurora and disturbance of the surface field are broadly related, the relationship cannot be regarded as simple or direct. When intense disturbance currents are set up, their presence may be manifested by active aurora, but their decay and the associated return of the magnetic field to normal can proceed without parallel auroral activity. This necessity of referring both the magnetic and auroral activity to a third process is also emphasised by the frequency with which a complete disproportion between the scales of intensity of the two phenomena can be illustrated.

1932 *August* 29.—Throughout the dark hours the sky was continuously overcast.

1932 *August* 30.—From the auroral aspect the distinctive feature of the display on this night was the succession of four waves of highly coloured, rapidly moving draperies which, between 7h 18m and 7h 57m, spread northwards from the south and south-east into the overhead sky. These outbursts were concentrated into the intervals 7h 18–21m, 7h 32–39m, 7h 45–49m, and 7h 51–57m; very fleeting coronas were formed in the last stages of each, and at least after the second and third the coronas dispersed by spreading out in draperies along the magnetic prime vertical plane. In the fourth wave the draperies were at times completely coloured purple-red, but alternated from this to all green.

These four auroral waves coincided with four unusual magnetic field movements of the type described in § 94 as "discharge and recovery." Fig. 21 illustrates a similar set of movements for another occasion. Over the two-hour period 6h to 8h the horizontal meridian field H was diminishing irregularly and the vertical component was rising, but at each of the intense auroral outbursts from the south sky the trends in these components were suddenly accelerated so that H fell 320 γ in not more than a minute at 7h 20m, increased 180 γ in the next minute after a sharp reversal, and then slowly (9 minutes) to its value before the sudden decrease. A similar process was repeated in each of the next three waves. The synchronous movements in Z were in the opposite direction, first an increase, a reversal, and then a fall, at first sharp and then more slowly. The phenomenon suggests that from 6h to 8h an EW. current system was being built up to the south of Fort Rae. Simultaneously with the onset of each wave of aurora, the process was suddenly accelerated and, for a brief interval, continued at a rapid rate. It then suddenly stopped and returned, at first rapidly then more slowly, to the stage it had reached before the sharp acceleration set in.

Additional noteworthy features are, firstly, that though their over-all scale was considerable, the movements were not so spectacular as might have been expected from the brilliance of the aurora and in comparison with the magnetic accompaniments to similar aurora on several earlier evenings; and, secondly, that though to-and-fro movements of both waves and rays along the draperies in the successive waves were extremely strong the magnetic effects were relatively simple.

The behaviour of the auroral and magnetic activities after the fourth outburst was interesting. Almost synchronously with the degeneration of the strongly structured aurora to a diffuse luminosity, H began to rise, and increased steadily through 550 γ till 8h 32m. Meanwhile, after continuing unsteady well above its mean value, Z fell much more slowly than H, though fairly regularly. The intermittent tendencies to recrudescence of moderate auroral activity in this period had no clear counterpart in the magnetic field. At 8h 32m Z suddenly fell 495 γ in two minutes, and recovered almost exactly the same amount in the next seven minutes; H on the other hand was affected by a sharp up-and-down oscillation of only 210 γ. For this isolated perturbation there was no auroral counterpart. A glow left from earlier activity had gradually disappeared, leaving only scattered patches of luminosity. This particular movement is to be considered as evidence that very large and sharp perturbations may be completely unaccompanied by aurora. In the notes of examination of auroral and magnetic phenomena so far given the evidence has been almost wholly of the other kind, viz. that strong auroral activity may be in progress without any magnetic counterpart.

August 31.—Continuously overcast.

September 1.—Continuously clouded or overcast; insufficient detail for comparison with magnetic disturbance.

September 2.—Overcast.

September 3.—Overcast.

September 4.—Clouded or overcast; no detail.

September 5.—From 5h to 8h aurora was observed continuously, mainly in the form of a persistent but variable arc stretching from the east to the west horizon through the overhead sky. Spasmodically, *e.g.* between 5h 40m and 5h 55m, from 7h 01m to 7h 12m, and *ca.* 7h 30m, the arc strengthened from moderate or rather weak to strong intensity and became structured in curtain form. But throughout these three hours the magnetic field was essentially undisturbed, what small (few γ) movements there were being slow and completely characterless.

Just before 8h an HA disintegrated into R tufts, which quickly developed first into a strong curtain and then at 8h 07m into a brilliant corona. Intensely active and highly coloured aurora continued with only momentary weakenings till 9h 11m. During this hour of sustained activity there were frequent examples of W. to E. wave movements in curtains; there were also two examples of to-and-fro movements, but none directed E. to W. Most of the activity started from the ESE. and extended through the zenith into the NW. sky.

From the viewpoint of the magnetic field, Z alone showed any appreciable movement (and in this only an increase of about 25 γ from 8h 07m to 8h 10m) till three minutes after the corona had formed; H began to fall in the same interval, but only at 8h 10m, when brilliantly coloured and quickly moving draperies had replaced the corona, did the scale of the disturbance vector become really noticeable. Even then H fell only 124 γ within a minute, and remained irregularly at or below this level during the remainder of the aurorally active hour. Z fluctuated above and below its normal value with a range of 250 γ in two considerable movements in the second half-hour when strong curtain activity was in progress.

The evidence of this display and the simultaneous behaviour of the magnetic field is that, for three hours, aurora which was at times both active and strong had no corresponding magnetic counterpart, and even when the aurora became brilliantly coloured and was in violent motion the surface field changes were both disproportionately small and had only a general relationship in time with the most active auroral phases.

September 6.—Though this display lasted from 3h 50m till 10h 20m, really active aurora was confined to the interval 6h 23m to 8h 01m, and more especially from 6h 23m to 6h 47m, when very strong curtain formations culminating in coronas with much violent movement were the chief features.

Up to 6h 23m all three components of the magnetic field were only slightly disturbed although aurora, albeit mainly weak, was continuously present. From 6h 23m to 6h 40m, with temporary set-backs at 6h 34m and 6h 39m, H fell through 495 γ, fluctuated about this level below its mean for ten minutes, and rose steadily until 7h 08m. In the same time Z first rose 180 γ from 6h 23m to 6h 40m, fell 325 γ to 6h 43m, and then, after a few oscillations below the mean, rose well over this mean through 395 γ between 6h 49m and 6h 55m. These movements occurred in the period of most brilliant aurora, and, on their simplest interpretation, indicate an atmospheric current system directed EW. and to the south of the station up to 6h 42m, when it moved to the north for about seven minutes and then back to south from 6h 53m. It remained south or overhead till 8h.

Up to 6h 38m the auroral activity was mainly confined to the southern sky, but on the disintegration of a corona at 6h 38m strong rayed activity spread northward, so that by 6h 40m most of the sky was covered with curtained forms. This is two minutes before the estimated time of migration of the current system from south to north of the station. Again, at about 6h 48m, a rayed band began to sweep across the sky from the NW. leaving the area swept completely free of aurora. The time of clearance of the north sky agrees approximately with the return of the current system from north to south. In this instance there is therefore considerable correspondence in time between the movements of the disturbance-producing current as deduced from the magnetogram and the aurora. It should be remarked, however, that throughout all this period of rayed auroral activity a homogeneous arc had remained persistent across the south sky. In conjunction with other similar instances already mentioned in these notes, it therefore appears that vertically structured aurora more closely corresponds with the true current system changes than aurora of the quiet homogeneous type.

In this same display there are two clear examples of the most considerable and sharpest field vector changes occurring at the times of appearance of corona. For example, at 6h 39m H fell 260 γ in little over one minute, and again, after a slow recovery movement, it fell 330 γ at 7h 18m. Both of these rapid changes synchronised with coronas or strong overhead drapery formations. The movement in the vertical field at 7h 18m was also the sharpest in the disturbance, Z falling 280 γ in two minutes.

September 7.—Following on a display in which occurred some good instances of correspondence between the auroral and magnetic events in regard to position as well as magnitude and time, the events of the 7th form at least a partial contrast. Though on this evening, too, the aurora assumed brilliantly coloured drapery and curtain forms with much motion, the simultaneous magnetic field changes were quite inconsiderable by comparison with those which frequently occurred about the same time on other evenings. Up to 5h 13m the aurora was in the form of a quiet arc which moved at 4h 58m from the north into the south sky. Apart from a gradual fall in Z, and a rise followed by a fall in H—both of which changes were too slight to be interpretable in terms of displacement from normal—the field was quiet up to 5h 16m. From 5h 16m to 6h 07m the auroral activity was almost continuously strong. In the four minutes 5h 27m to 5h 31m very active curtain formations in the southern sky mounted towards the zenith, formed a corona at 5h 28m, and moved into the north sky. Meanwhile H was diminishing slowly and Z rising in a manner indistinguishable from that at other times when auroral conditions were quiet or absent. There was no magnetic counterpart to the corona at 5h 28m, and even when the strongly curtained formations moved into the north sky the greatest change in both elements was 60 to 70 γ in two minutes. Near the end of this active stage of the display (5h 59m–6h 07m), when an overhead rayed arc developed into highly coloured draperies in violent motion, the only sharp movement in the disturbance occurred, viz. a fall of 145 γ in Z in three minutes, and a slower drop in H of 120 γ in four minutes. Both of these movements, it will be recognised, were quite inconsiderable on Fort Rae standards.

The aurora continued till 10h 25m, but with no particularly noteworthy features: the intensity in the later stages was generally not more than average, though for short intervals (7h 20–25m, 8h 16–20m, 8h 51–55m, and at 10h 9m) it strengthened to 3 on the 0 to 4 scale. Throughout the whole of this time the surface field was disturbed, but with no extraordinary movements. During the periods, 6h 03–30m, 7h 00–40m, and 8h 10–40m, when Z was below its mean value with H irregular about normal (so indicating either an EW. current system far to the north of the station or a WE. current to the south), the only quasi-persistent feature of the aurora was a homogeneous arc across the south sky. But throughout its life other activity was in progress in the north and overhead sky. The greatest movement of the night was still proceeding when aurora had degenerated to a glow at the end of the display.

The degree of correspondence between the two phenomena throughout the display of this evening was slight.

September 8.—The striking feature of the magnetic disturbance on the 8th was the early and large depression in both H and Z. From 2h to 4h 10m, and more especially from 3h 10m to 4h 05m, both elements were 200–300 γ below their mean values, indicating the unusual phenomenon of a disturbing current lying to the north of Fort Rae. Even in the subsequent stages of the disturbance up to 10h the main movements in Z and all in H were made below the normal, so that on the magnetic evidence the current system remained northward of the station throughout the display (3h 15m–10h 00m). The auroral observations were largely vitiated by a persistence of cloud, but the descriptive notes indicate that the activity was very largely confined to the north or overhead sky.

The first very active auroral phase occurred between 3h 20m and 3h 35m, when, in spite of strong twilight and an almost completely overcast sky, colouration and much movement was observed overhead though probably to the north of the magnetic prime vertical plane. Between 3h 15m and 3h 25m Z fell 540 γ, and H, which had fallen an almost equal amount from 3h 00m to 3h 20m, rose sharply to 3h 25m in a partial return to normal. Immediately after 3h 25m, aurora, as judged through the veil of cloud, subsided, and further details were mainly uncertain till after 7h. At about 6h 15m, however, when unmistakably strong activity was in progress in the overhead sky, Z fell 300 γ in two to three minutes and at the same time H suddenly reversed in a symmetrical down-and-up movement of nearly 200 γ range.

Later in the display, when details of auroral form, intensity, and position could be observed with more certainty, the closeness of correspondence was not improved, and further examples of strong activity without any noteworthy magnetic counterpart were common. For example, at 7h 50m a corona was formed and was followed by much curtain activity in the high north or overhead sky till 8h 02m. In these twelve minutes the field changes were insignificant compared with others in progress when the aurora was much quieter. Again, at 9h 18–20m, towards the end of the display, a strong rayed arc developed into a curtain with violent WE. movements: the curtain then moved bodily into the south sky. But apart from a 40 γ dip in H, the field was quiet.

September 9.—As on the previous evening, the display was marred until 7h by cloud, and unfortunately it was in this period that the major magnetic perturbations occurred. The auroral activity from 7h 00m to 10h 30m was spasmodically very strong, particularly in the intervals 8h 04–08m, 9h 27–38m, and at 9h 53m and 10h 55m. At each of these times curtain or drapery formations (at times forming coronas) with much to-and-fro movement and colouration were the prominent features. But throughout the whole of this three-and-a-half hour period the magnetic field was affected by no individual movement of significant magnitude or speed. It is noticeable that during the short interval 9h 02–10m, when auroral activity was all but completely absent, the magnetic field changes were not conspicuously different from those at other times during the latter part of this display.

Any correspondence between the aurora and magnetic disturbance on this evening must therefore have been confined to the early stages when the auroral events could not be observed in detail.

September 10.—Up to 8h 40m the magnetic field was completely quiet, but probably from 4h, and certainly from 6h, auroral activity, though weak, had been continuous. Immediately after 8h 41m a rayed arc developed into a very bright and active curtain across the south sky: violent wave and ray movements continued till 8h 51m, when the activity subsided. Z increased slowly and steadily by the insignificant amount of 25 γ from 8h 41m to 8h 51m and fell again equally slowly; the effect on H was even less noteworthy. The only other feature of interest about the perturbation in addition to its completely disproportionate size in relation to the concomitant aurora was the agreement between the position of the disturbing current deduced from the directions of movement in the force components and the position of the aurora.

From 9h 02m to 9h 20m there occurred more very strong curtain and drapery formations accompanied by much agitation and high colouration, at times converging in complete or partial coronas and at other times filling the whole sky. But the magnetic field changes continued to be quite small. Presumably associated with the dominantly overhead position of much of the activity in this period, the movements in the vertical field were sudden, but apart from the fall in both H and Z at 9h 11m between two coronas no individual perturbation exceeded 50 or 60 γ.

From 9h 20m till 10h 10m similar extremely active and bright aurora continued: more or less complete coronas were noted at 9h 35m, 9h 55m, 9h 56m, 10h 03m, and 10h 04m, and curtain and drapery formations were almost continuously present. Apart from sudden but slight oscillations noticeable only in Z, the magnetic field remained comparatively unaffected. The events of this evening formed the best illustration to date of complete lack of proportion between the two phenomena.

September 11–12.—Continuously clouded or overcast.

September 13.—Aurora was first noted at 3h 50m, and from then till 6h 30m was mainly in the form of a weak, quiet arc system in the north and overhead sky. Throughout this time the magnetic field was only slightly irregular though with the vertical component somewhat depressed and the meridian horizontal component about normal, so that the disturbing vector might have been related to an EW. current lying northwards of Fort Rae. From about 6h 30m, when a rayed arc formed across the south sky, Z slowly increased and H decreased in keeping with the formation of a new current system to the south of the station. But even when the arc developed into a strong curtain, which extended rapidly upwards between 6h 55m and 6h 57m, the field movements continued to be small. At 7h 03m, when the curtain developed into a drapery and became very strongly coloured in emerald green and was affected with much violent movement, both H and Z were suddenly depressed through about 300 γ in a minute or less. The coincidence in time between this perturbation and the very strong overhead auroral activity culminating in a corona was unmistakable. The continuation of this very brilliant aurora in the next five minutes, however, had little further effect on the magnetic field.

It is from such a stage as we have now reached in the analysis of the simultaneous events of this display that further comparison between the two phenomena usually becomes difficult. Before one phase of auroral activity has subsided and while the field is still disturbed, fresh auroral forms appear in other parts of the sky and disentanglement becomes quite impracticable. Only the strongest new outbursts can be isolated and compared with disturbance.

Between 7h 37m and 7h 46m another bright curtain system developed from a rayed arc and continued till 7h 55m with very rapid ray and wave movements culminating in coronas at times. In this phase H underwent rapid and repeated but unspectacular oscillations, while after having recovered from the first depression Z fell irregularly from 7h 36m and then suddenly through 290 γ in little over a minute at 7h 49m. It recovered again almost immediately in a series of very quick oscillations.

A further short interval of very strong aurora occurred from 9h 01m to 9h 05m, again in the shape of a rapid development from a rayed arc to coloured draperies which converged with much rotary movement to form a purple corona at 9h 03–04m. Like similar phases in the display of the previous evening, this extremely active auroral interval was represented in the magnetic field by almost insignificantly slight irregularities. Despite the remarks in a preceding paragraph concerning the difficulty of disentangling the phenomena in the later stages of a display, it would seem from this and earlier examples that even when correspondence in time and some proportion in scale of the activities are recognisable, this correspondence is mainly confined to the earlier stages of displays. As the aurora proceeds, especially if after midnight, the magnetic field changes may bear little or no relation to the aurora.

September 14.—Sky overcast throughout the dark hours.

September 15.—From 5h 50m to 7h 08m neither of the force components were sufficiently disturbed for comment, although an arc persisted across the south sky. At 7h 08m a rayed arc developed in the SE. sky and, after rapid change to very bright curtains and draperies with much colour and agitation, formed a corona at 7h 12m. Within a minute of the formation of the corona both H and Z suddenly fell 180 γ in a minute, the fall in H being from its quiet condition, that in Z after a sudden sharp rise of 45 γ in the preceding minute. This is a further example of close correspondence of the two phenomena in the first stages of a display. During the subsequent five minutes, when the drapery activity was rapidly waning, the field vectors were further reinforced in the direction of decrease of the main field but to the extent of only 70–80 γ From 7h 19m to 7h 40m the H and Z components remained depressed, but, with intermittent irregular fluctuations, were gradually recovering their normal values. The oscillations superposed on the irregular recovery coincided approximately with minor fresh outbursts of rayed activity. At 7h 56m another short but intensely active phase of the display started and continued till 8h 04m in drapery formations which possibly converged at times in coronas. In this phase H, which by now had completely recovered its normal value, underwent a sudden sharp drop of 250 γ in under a minute (at 7h 59m), while, centred at the same time, Z suffered a quick oscillation of 180 γ about its mean value. When the aurora in this outburst was rapidly waning between 8h 05m and 8h 12m the field continued to be disturbed, and in the next 14 minutes, to 8h 26m, when auroral activity was almost completely absent, both H and Z were changing fairly rapidly and irregularly. Within this lull interval the direction of change of both components reversed abruptly about 8h 19m. A subsequent intensification of an elliptical rayed band at 8h 56m was only weakly reflected in magnetic disturbance, and again towards the end of the display the field was comparatively quiet from 9h 30m to 10h 00m though moderate aurora continued.

In this example of comparatively simple aurora and magnetic disturbance there are therefore clear instances of close agreement in time between outstanding phases in the two phenomena especially in the earlier part of the display; towards the end the agreement is less close.

September 16.—Throughout the night of the 16th the magnetic field remained completely quiet; the whole day was one of the quietest of the year. In keeping with this, the night was remarkable for its negligible auroral activity. Aurora was observed between 8h 00m and 8h 16m, but except at about 8h 10m, when it just attained moderate brightness, its intensity was weak. The condition of the magnetic field in this quarter-hour could not be distinguished from its general quietness throughout the evening. Discounting the merely momentary strengthening of the aurora, the agreement in complete absence of both aurora and disturbance on this evening is noteworthy.

September 17.—In opposition to the inferences drawn from the events of recent evenings, those of the 17th illustrate the formation of coronas from strong curtains in the early active phases of a display without any significant field changes.

From 5h 20m the dominant feature had been a quiet arc with some rayed structure which, until 5h 45m, was at least of moderate intensity and thereafter weakened till its complete disappearance at 6h 12m. H throughout this interval was quite quiet, while Z sluggishly diminished through 20 γ from 5h 20m to 5h 45m and then recovered as the arc weakened. From these field effects it would be deduced that the responsible current system was either far to the north and directed EW., or directed WE. and far to the south. Actually the main part of the arc was situated in the upper south sky, and at least about the time of its maximum intensity was observed to be traversed from E. to W. with a bright luminous patch. Even at this simple and early stage of the display the magnetic phenomena were therefore not referable to simultaneous auroral events.

Between 6h 20m and 7h 00m a fresh auroral feature in the form of a rayed arc steadily strengthened, became very active at 6h 28m, and developed into a strong overhead curtain with much movement. Spasmodically between 6h 28m and 6h 37m coronas formed which were at least partially complete. In the same interval the magnetic field remained quiet except for a slow and shallow irregular bay movement of 30 γ in H and some small oscillations of 10 γ range in Z. During a further interval of brightly coloured and very active draperies between 7h 28m and 7h 34m, with a corona at 7h 29m, the field components were slightly more disturbed, but still only in a minor way. The greatest individual movement (about 100 γ in H and 70 γ in Z) occurred at 7h 30m just after the corona had re-dispersed into draperies which speedily covered the north sky. Aurora persisted till 10h 32m, at times with strong curtain formations and much motion, but the field changes were comparatively small and slow.

§ 123. *General conclusions from the analysis of auroral activity and magnetic disturbance.*—In the foregoing section the auroral events and concomitant magnetic disturbance on each of the evenings from 1932 August 17 to September 17 have been examined in some detail. The general inferences from the complete analysis may be summarised as follows:—

(1) Strong and active aurora of a vertically structured type (rayed band, curtain, and drapery), especially when in the overhead sky, is frequently, but by no means invariably, accompanied by very large magnetic perturbations in which the meridian force components change by several hundred gammas in a very few minutes.

(2) Though the times of the sharpest and most spectacular movements in these perturbations frequently coincide with the most active phases of an auroral display, there are occasions when the chief magnetic movements are out of step with the peaks in auroral activity. It may not be till after an intensely bright rotary corona has dispersed into draperies oriented along the magnetic prime vertical plane that the main vector change shows itself in the surface field. Again, the bodily migration of bright aurora from the north to the south sky or *vice versa* may precede by a few minutes the reversal of that perturbing vector component which indicates a similar change in the position of the current system.

(3) Examples of simultaneous activity on a large scale in auroral and magnetic

disturbance occur more frequently in the early than in the late phases of a protracted display. When apparently equally intense and similarly structured and positioned aurora occur twice or more in an evening, the magnetic field changes at the time of the later outbreaks are generally smaller than those accompanying the earlier outbreaks.

(4) Even when two intervals of intense activity follow quickly on each other and appear to go through exactly similar evolutionary stages and reach the same degree of intensity, the concomitant perturbations in one or other component of the magnetic field may be reversed.

(5) Disparity between the scale of intensity of the two phenomena is not only evident between the earlier and later phases of the same evening's display. Throughout an entire display the magnetic field changes may be continuously damped compared with those on another evening of similarly strong aurora. Not infrequently a succession of very active outbursts of aurora repeatedly culminating in those forms with which the greatest field changes are usually associated is accompanied by almost insignificant magnetic disturbance.

(6) Such evenings of uniformly disproportionate relationship tend to occur in batches as do those in which the relationship is better defined.

(7) Disparity in scale of the two phenomena is not associated only with the strongest aurora. On occasion, aurora of moderate intensity interspersed with brief intervals of active and strong aurora has continued for several hours with no appreciable simultaneous changes in any of the field components. Conversely, examples have been found when considerable magnetic disturbance was in progress but when no aurora or aurora of an inappreciable intensity and area of sky covered has been observed.

(8) Despite these occasions of complete lack of agreement in scale of the two phenomena, nights of strong aurora are generally nights of greatest magnetic disturbance, and, even more rigorously, poor auroral displays are invariably associated with the periods of most complete quiet in the magnetic field. This latter statement is true to the extent that even though the diurnal variation of irregular disturbance is normally at a maximum near the midnight hours, night hours of negligible aurora are usually as quiet or quieter than the day-time hours.

(9) While the first movement in a large perturbation commonly takes place simultaneously with a strong outburst of aurora, particularly if in the overhead sky, the subsequent movements (which are seldom so sudden) proceed with little relation to auroral events. Even when the outbursts of auroral activity which occur immediately after the first phase of a magnetic movement and before the field has recovered are as strong as those which accompanied the initial movement, they are frequently associated only with minor set-backs or superposed irregularities in the return movement.

(10) Though on occasions of isolated auroral forms, especially if these are horizontally extensive (arcs, bands, or curtains), the aurora might be the seat of the atmospheric disturbance current responsible for the changes in the magnetic field, the positions of the auroral forms more often give little clue to the mechanism of the magnetic field displacements. Aurora as observed at the station may be confined to the north sky at the same time as the only valid interpretation of the direction and magnitude field vectors requires the disturbance current to lie to the southward and conversely.

(11) Similarly the direction of propagation of wave or ray movements along a structured auroral form is no guide to the direction of the disturbing current. But on at least one occasion at Fort Rae a reversal of wave motion in a curtain coincided with a rapid change in direction of the horizontal force vector.

(12) Aurora of a red, crimson, or purple colour is in general associated with greater disturbance than when the colour is the usual greenish yellow. But since such unusual colouration is most frequently associated with those structured and intensely active forms (curtains, draperies, and coronas) which are already more

generally associated with greater magnetic disturbance than other auroral forms, this inference is probably not an independent one.

(13) No examples of disturbance of any appreciable magnitude have been found when a homogeneous arc was the only auroral form; the persistence of a homogeneous arc has seldom been accompanied even by a steady displacement of the field. On the other hand, the development of rayed structure in such an arc was observed to occur simultaneously with the appearance of oscillations in the field components after a quiet period.

(14) Magnetic perturbations which occur when daylight is too strong for aurora to be observed are often not less great than, and have no characteristic features which distinguish them with certainty from, those perturbations which occur in the auroral hours.

(15) Rapid formation or bodily movement of curtains, rayed bands, and draperies are more frequently accompanied by rapid field changes than when the same curtains are stationary but are affected by much violent internal wave or ray motion.

(16) In the process of clearing the widespread, diffusely structured luminosity, which is frequently the aftermath of a very active outburst, the formation of an arc along one horizon and its progress across the sky may be accompanied by rapid changes in the magnetic field vectors.

(17) Owing to the frequency with which several auroral forms co-existed in the sky at such a station as Fort Rae, it is very often impracticable to associate uniquely a particular magnetic perturbation with any one auroral form. It is this same liability for several forms to occur at one time that frequently precludes direct correlation in all but the initial stages of a display. In the later stages only the strongest fresh outbursts can be compared with disturbance.

(18) In spite of the frequent agreement in time and scale of the magnetic disturbance and auroral activity it is difficult to avoid the conclusion that the two phenomena are only loosely associated. The position, direction, and magnitude and even the presence of the complex electrical current system responsible for the magnetic perturbing vectors at any one instant can seldom be rigorously related to the simultaneous auroral phenomena. It would appear that it is only when the current system is rapidly modified or readjusted in position, direction, or magnitude that such adjustments may be manifested in aurora. The form of the aurora depends on the nature of the adjustment in the current system but is not rigorously related to it. A change in the concentration of lines of current flow at, say, 500 km. may be manifested by an aurora at 100 km. of the same form as a change in concentration at 150 km., but the magnetic effects at the earth's surface, both direct and indirect, will be vastly different.

(19) In earlier parts of this discussion it has been established that short period irregular disturbance at Fort Rae is most frequent, and probably also greatest in scale, in those hours near local midnight when auroral activity is also greatest in (*a*) simple frequency of occurrence irrespective of form, (*b*) intensity, and (*c*) occurrence of special types such as coronas, draperies, and curtains. And a similar general trend of parallelism has been shown to extend to the seasonal as well as to the diurnal variations in auroral activity and magnetic disturbance. It was therefore impracticable to disentangle the two phenomena so long as examination was confined to broad statistical lines. Throughout the examination of the corresponding auroral and magnetic data described in foregoing paragraphs, therefore, evidence has been sought to answer the question whether any characteristics of magnetic disturbance could be associated uniquely with any particular auroral forms, or, more generally, whether the disturbance during aurora of any type or intensity differed from that which occurred at times of the day when aurora could not be seen. The answering of such a question either in its particular or general form is of importance. Because if any one characteristic of disturbance could be shown to be invariably associated with the presence of aurora, the detection of this characteristic at a time of the day when aurora could not be observed could be construed in one of two ways, either:—

(i) That aurora, whether above or below the horizon, is not in itself a necessary accompaniment to the production of disturbance, or

(ii) That aurora may be present in daylight.

Now part of the evidence of the examination detailed in § 122 is that at least those sudden, sharp, and large scale changes in the magnetic field which introduce N disturbances very frequently synchronise with strong draperied activity. But even in the dark hours very large and abrupt field changes have been found to occur with no corresponding aurora above the Fort Rae horizon. And as has been explained in the description of the typical M disturbance, equally rapid field changes may take place in the daylight hours.

Taken in conjunction with the general summary of inferences in the preceding paragraphs, the conclusion from the magnetic point of view must therefore be that there is nothing unique about the form of disturbance associated with aurora.

From the other aspect, aurora was observed early in the evening while twilight was still strong; it was also observed so late in the morning that it seemed to be only the strength of the twilight which precluded later observation and not that the aurora itself stopped. It was observed late in May when twilight was strong throughout the night and when the difference between ionisation conditions in the high atmosphere in the day-time and in the night hours must have been slight. Moreover, though the photographic results have not yet been examined sufficiently to decide whether aurora occurred in the sunlit atmosphere at Fort Rae it has been shown to occur in Norway. Neither the magnetic nor the auroral evidence, either separately or together, is therefore against the possibility of aurora occurring in daylight, so that until some other method is devised of determining whether or not aurora, as it is observed in the dark hours, can exist in daylight also, there is no evidence for regarding it as inseparably linked with magnetic disturbance.

Although reference has been made in the General Introduction to this volume to the parts played by the several members of the expedition in the work at Fort Rae, I cannot close this part of the discussion without expressing personal and very sincere thanks for the assistance given me in carrying out the programme of magnetic and auroral observations. That the magnetograph records are as complete as they are is due almost entirely to the continuous care and enthusiasm of Mr Grinsted, to whom fell the maintenance of illumination for the recorders and the accuracy of their timing, and the changing and developing of the charts. Mr Grinsted also spent much of his spare time at Fort Rae tabulating the magnetic records; in this he was assisted by Messrs Stephenson and Sheppard. For a great proportion of the important and sometimes irksome control observations with the Smith magnetometer and the dip inductor I am indebted to Mr Sheppard; and for the comparison observations, using the Kew magnetometer and dip circle on the site of Old Fort Rae, to Messrs Stephenson and Morgans. The determination of the azimuth marks for declination at both stations was done by Mr Stephenson.

In the present volume it has been possible to give only very partial consideration to the great mass of visual auroral observations made at Fort Rae, and none at all to the results of the auroral photography. About 900 simultaneous pairs of photographs have been measured by the Norwegian technique, so that, on a conservative estimate of twelve selected points on each photograph, positional details for 10,000 auroral points are now available. It is intended that the analysis of these measurements and the discussion of the results should form the subject of a future additional volume. In the meantime it is a pleasure to record the valuable cooperation in the heavy programme of auroral work given by Messrs Morgans, Sheppard, Stephenson, and Grinsted, who shared the duties equally. In so far as these involved long watches throughout the night, with exposure to very low temperatures, for the greater part of the time, they were probably the most arduous of the expedition's activities.

§ 124. BRIEF SUMMARY OF AURORAL NOTES FOR A REPRESENTATIVE PART OF THE AURORAL SEASON 1932 AUGUST 8–SEPTEMBER 17 (SEE § 112)

August 8.

h m h m		Average Intensity.
04 30–04 45	HB in SE., seen in strong twilight with pink colouration.	
04 45–06 00	Lull.	
06 04–06 20	Long straight A (HA?) through zenith extending NW.	2 +
06 25–06 30	Lull; only weak DS.	
06 30–07 27	Multiple weak arcs (HA $\rightleftharpoons$ RA) across overhead sky with occasional diffuse R.	
	Lulls (in which activity degraded to DS or less) at 06.41, 06.50, 07.00, 07.17 to 07.27.	
07 27–07 31	RA in SE. → RB intensified to 3 – and waned.	
07 31–07 38	Multiple RB with occasional R and RB patches: strongest at 07.35.	2, 3
07 40–07 50	Lull.	
07 51–08 20	HA → RA in NE., with HB and HA in high S. and overhead sky (3 – momentarily at 08.01).	2
08 20–08 55	Weak HA in high sky parallel with M.P.V. (magnetic prime vertical plane through station).	

August 9.

h m h m		
04 50–04 54	RB → DS in S. sky; very strong twilight.	
04 54–05 01	RB again in zenith after disappearing at 04.55.	
05 01–05 54	RA in SE. sky extending to zenith; multiple A formations mainly E. degenerating spasmodically to DS; always weak and diffuse.	
05 55–05 59	HA through zenith → RA intensified to 3 – and quickly weakened again → R patches.	
06 00	Only weak R pencils in SE. and narrow bands overhead.	1
06 01–06 13	Arc in zenith (with lull at 06.07).	
06 13–06 41	No note of activity: probably lull.	
06 41	HA in SE. intensified, with colouration.	2 +
06 42–06 45	RB and R patches SE.	
06 45–06 50	R → irregular Cn → D → Corona; very bright and quickly moving. Corona 06.47 rotating. Corona 06.49 with colouration.	3 +, 3
06 51–06 56	RB and R in high sky (2 + at 06.52).	1
06 57	No noteworthy activity.	
07 08–07 30	RA (temporarily strong to Cn 07.13) in high sky.	1
07 31–07 52	Activity again suspended except for isolated R.	
07 52–07 53	HA → RA → Cn → C; much movement. Corona at 07.52.	3 +
07 54	Activity disappeared.	
07 57–08 18	Parallel RB and RA bands SE.; diffuse HA (2 + at 08.04).	1

August 10

h m h m		
06 27–07 00	Weak HA, RB, and R activity; all poor.	0 +, 1
07 01–07 02	RB → 3 in high SE. sky and quickly waned.	3
07 03–07 09	RB, SE. to NW.	
07 10–07 11	RB → Cn or D; quickly waned.	Momentarily 2 +
07 12–07 21	RB and R masses → D → Corona. Quick movements in D in overhead sky. Corona at 07.13 and 07.16.	3 + or 4
07 21	Overhead activity almost disappeared.	
07 22–07 53	HA, RB, etc. (NW. to high sky).	1
07 54–08 00	Cns and D rapidly developed with much movement in overhead sky.	3
08 00–08 39	Mainly weak RA and HA bands in SE. and high S. sky. Intensity 2 at times but interspersed with complete lulls (*e.g.* 08.20, 08.26).	1, 2

August 11.

h m h m		
07 12–07 57	RA, HA, and R; no special features in poor display.	0 +, 1

Brief Summary of Auroral Notes (contd.)

Time	Notes	Average Intensity.
August 12.		
h m h m		
07 30–08 00	Illumination behind cloud.	
August 13.		
h m h m		
07 32–07 35	R patches in S. sky mounting to zenith.	
07 35–07 44	R → Cn → C with R patches throughout sky.	
	Much convoluted and circulating movement in Cn.	At times 3
	Corona 07.37 and 07·39, but second weak.	
07 45–07 54	Only DS and isolated R pencils.	0 +
07 55–08 17	Long RA's and R tufts SE. to NW. and overhead.	1–2
08 19–08 20	R → Cn, rapid movements along lower edge of Cn.	Momentarily 3
08 22–08 26	R, RB, and Cn in W.; weak.	1
08 27–08 30	R → Corona with much folded drapery; very bright.	3 +
	Corona lasted 08.27.25–08.29.54.	
	At 08.29 Corona widespread fanwise.	
08 30–08 33	Cn and D overhead, waned and reintensified.	2 +
08 34	R → DS.	
08 35–08 42	RB intensified → R → D in SE. and overhead sky.	3 +
08 43–09 10	RA and R, RB and HA mainly in overhead and S. sky and mainly weak.	1, 0 +
	At 09.06 long R in zenith tending to form very weak Corona.	
	At 09.08 activity almost suspended except for intermittent R.	
09 11	RB temporarily formed weak Cn; quickly dissipated.	2
09 12–09 52	RA and RB.	0 +
August 14.		
h m h m		
05 50–06 02	Quiet HA along S. and SE. horizon.	
06 03–06 17	HA persists; R and RB in SE.	1
06 17–06 29	Sudden appearance Cn; vivid yellow green in S.	2 +
	Cn formations persist till 06.29; much colouration and movement.	At times 3 +
	Corona tendency 06.19 and 06.23.	
	Persistent HA(?) both along SE. horizon and overhead during much of activity.	
06 30–06 49	Multiple parallel arc system across S., high S., and overhead sky.	1
	Systems of R pencils from SE. and NW. horizon (converging to weak Corona 06.38.26).	1 –
	RA across upper sky moving south; 2 + at 06.42, and weakened.	Momentarily 3
06 50	Only weak HA.	
06 51–06 54	RA → HA steadily falling to S. horizon from overhead.	2
06 54–07 01	HA → RA → R → Cn quickly increasing elevation and brightening.	
	Much to-and-fro movement and colouration in RA and Cn.	3 +
	Corona 06.56. Quickly rotating.	
07 01–07 16	Only isolated weak R patches and weak HA.	0 +
07 17–07 24	Cn formations in N.; much convoluted.	3
07 25–07 49	RA and RB systems mainly N. and weak.	1–2
	S. sky completely quiet at 07.29; only weak DS in NE. and N.	
07 49–07 54	R → Cn in high N. sky.	At times 3 –, 3 +
	Much wave movement (NW. to SE.), and some colouration.	
07 56–08 10	RB becoming Cns again at times and rotary.	
	RA (08.09).	2
08 11–08 37	RA and RB; weak.	1
08 38–09 12	RA and RB mainly in S. sky: at times 2.	Mainly 1
	At 08.33 almost negligible activity.	
09 12–09 25	HA quiet and weak across S. sky.	1
	Features: More general activity in N. than S. sky in later part of display.	
	Sudden development of Cn from quiet HA (06.17).	
August 15.	Continuously cloudy.	
August 16.		
h m h m		
06 10–06 21	HA in ESE. sky, weak and diffuse, increasing altitude; some DS and R patches in E.	1
06 22–06 23	DS in E. → R → Cn (partial), then dissipated.	Temporarily 3
06 23–06 36	HA overhead → RB; RB in E.	1 to 2

Brief Summary of Auroral Notes (contd.)

August 16—*ctd.*

h m h m		Average Intensity.
06 40–07 07	Spasmodic disintegration of HA to RA and RB all very weak. (06.49 wave movements RA, N. to NW.)	0 +, 1
07 08–07 15	Lull.	
07 15–08 42	R tufts in E. or SE.; multiple HA, SE. to NW.; persisted throughout; weak generally except for occasional R tufts (2).	1 +
	Intervals of cessation of activity 07.44, 08.24, 08.32. Activity mainly in N. hemisphere.	
08 42–08 48	Multiple arc, HA → RA → RB, sharp on N. edge, diffuse to S.	3, 3 +
08 49–09 03	HA disappeared, RB and elongated DS.	1
	Features: In this display almost complete absence of real activity of Cn form, except momentary tendency at 06.23.	

August 17.

h m h m		
08 01–08 13	RA and RB in SE. and S.; also HA along S.	
08 13	Bright R in high S. towards zenith.	3
08 14–08 43	Continuing weak or moderate. R, RA, and RB confined to S. hemisphere.	
	At 08.21 all activity to S. of M.P.V.	
08 43–08 47	Lull.	
08 47–09 03	No note of activity.	
09 03–09 19	RB → Cn in S. and W.; much colouration and movement, filling high sky and gradually extending all over.	At times 4
	Corona 09.09 and 09.11.	
09 20–09 22	Activity waned.	0 +
09 25–09 28	Cns waving and convoluting in high S. and overhead sky; bright and coloured.	3
09 31	Activity disappeared.	
09 38–09 54	Isolated R and RB and HA in S.	

August 18.

h m h m		
06 25–07 46	Generally quiet multiple parallel HA and RA systems mainly in high sky; generally diffuse and uninteresting. At 07.15 to 07.16 assumed D formation transiently, 2 +; therefore probably all RA seen from below.	1–2
07 46–08 02	No activity.	
08 02–08 20	RA and RB in W.	At times 2
08 20–08 29	RA and RB; with much wave movement: weak D at 08.22.	2 + and 3
08 29	All activity waned.	0 +
08 30–08 35	RA and RB.	1 to 3
	Up to here activity confined to S. of M.P.V. almost entirely.	
08 36–08 52	RB and RA continuing with luminous waves.	2, 1
08 52	Corona (3 +) very brilliant; much folding and wave movement along Cn.	3 +
08 52–08 55	Much strong Cn activity. Waves E. to W.	3, 3 +
08 55½	Lull; only isolated R.	
08 56–09 07	RA convoluted.	1, 2
09 08–09 15	Much Cn activity in overhead sky. Tendency to form Corona at 09.09.34: rapid wave movement and strong colouration.	2 +, 3 +
09 15–09 18	Irregular R and DS weakened.	1
09 19	R → Cn (3), quickly degrading again.	
09 20–09 24	Rapidly waning activity.	
09 24–09 29	Practically no activity of note.	
09 29–09 44	R and RB, 2 + temporarily.	0 +, 1

August 19.

h m h m		
05 43–06 27	Mainly quiet multiple A systems in overhead or high S. sky.	0 +, 1
06 28–06 35	HA → RB in SE.; waves of R.	2 +
	HA further S. persisting, then → DS.	1
06 36–06 37	R patch in DS.	1
06 38–06 43	HA in S. → RA with ray and wave movements.	1 +
06 44–06 52	Diffuse R masses over quiet HA, high S. sky.	
06 52	All activity up to now confined to S. sky.	

Brief Summary of Auroral Notes (contd.)

August 19—*ctd.*

h m h m		Average Intensity.
06 52–06 58	RB → Cn but never very bright or active: 3 momentarily.	2
06 59–07 05	RA(B) overhead, strengthening slightly and tending to Cn form again, but only momentarily; very diffuse.	2
07 06–09 46	Overhead HA and straggling RA and RB always weak and diffuse. At times (08.30, 09.16) complete suspension of activity.	1
	Features: In general, 05.43–06.52 activity to S. of M.P.V. 06.54–08.00 activity to N. of M.P.V. Mainly all diffuse A formations in overhead sky. Vague tendency to weak Corona at 07.07; never matured.	

August 20.

h m h m		
05 13–07 22	Mainly diffuse, multiple A system in overhead or S. sky. At times (06.27) HA → RA with wave movements, then → DS. Temporarily 2.	Mainly 1
07 22–07 41	Very weak DS and diffuse HA.	0 +
07 41	No activity.	
07 42–07 56	No notes.	
07 57–07 59	RB → Cn in NW. sky. Much movement and colour transiently.	3
08 00–08 07	R patches NW.	1
08 08–08 12	Rapid development of Cn, D, and Corona from RB. Brilliant colouration, much movement and rotation. (Semi-corona 08.10.39.)	3
08 13–08 14	Irregular R.	1
08 14–08 16	RB, weak wave movements, NW.	Temporarily 3 –
08 17–08 31	RB, RA, and HA.	1
08 32–08 42	RB → Cn in NW. with wave movement and colouration; waning spasmodically.	2 to 3
08 43–09 00	Weaker R and RB in high NW.	1 to 2
09 00–10 20	RA and HA in S. sky: occasional feeble Cns; 2.	1

August 21.

h m h m		
04 50–05 20	RA, RB, and R mainly in SE. and overhead sky.	At times 2, 2 +
05 20–05 36	Multiple Cns overhead, with much movement at times both WE. and EW.	3
	Cn movements strongest and aurora brightest at 05.29.	3 +
05 36–05 50	RB and RA in S., W., and NW. sky.	1 to 2
05 51–05 54	Cn and active RB in W. and NW.; wave movements EW.	3
05 55–06 00	Arc (HA or RA) low on S. horizon; narrow and clear cut. Also RB in overhead sky.	2
06 01–06 14	Much overhead Cn activity, with fold and wave movements in Cn. HA in S. sky persists till 06.38 (when with increased elevation it disintegrated to RB).	2 +, 3
06 15–06 37	R and RB mainly in W. sky; at times developing to Cn overhead.	2
06 38–07 01	Intermittent very active bright Cns. Wave movements in both directions.	At times 3 +
	Corona (06.49 and partially at 06.55); activity moved from predominantly in S. sky to mainly in N. sky.	
07 01–08 22	Intermittent bright RA and RB (at times intensity 3 +, *e.g.* 07.22). Frequent disintegration of apparently quiet arcs (HA or RA) into R, *e.g.* 07.30.	1 to 2
	Activity from 07.01 to 09.05 mainly to N. of M.P.V.	
08 29	No activity.	
08 36–09 05	Intermittent slight activity DS, R, and RB.	

August 22.

h m h m		
06 50–07 10	Weak HA overhead, and some feeble R.	1
07 10–07 28	HA → RB → DS; R in NW.	1
07 31–07 38	Lull.	
07 38–07 47	HA across S. sky.	1
07 47–08 12	HA → RA → Cn; very bright, highly coloured, and much violent movement at times.	3 +
08 13–08 31	HA again in S. and patches of R.	1

August 22—*ctd.* *Brief Summary of Auroral Notes* (contd.)

h m h m		Average Intensity.
08 32–08 37	R → RB → Cn with brilliant colouration temporarily; much movement.	3
08 38–08 49	Long irregular RB in S. sky.	1 to 2
08 49–08 53	RB → Cn, much violent movement and red-purple colouration overhead.	3 +
08 54–09 37	Quiet RA and HA form: 2 at times.	Mainly 0 +, 1
August 23.		
h m h m		
05 05–05 38	HA low across sky.	1
	RB systems in E. and NE. sky, at times bright (3). Active, with colouration, *e.g.* 05.23.	2
05 39–05 44	Rapid formation of Cn and D systems from RB; much brilliant colouration and violent movement; whole overhead sky full of rotary movement.	4
	Corona at 05.42.35.	
05 44–06 02	Cns spasmodically bright and active but generally weaker and more diffuse: very active at 05.52 and 05.55, and tendency to Corona at 06.01.	1
		3
06 03–09 56	Arc systems (RA and HA) mainly to N. of M.P.V., generally diffuse and weak.	1
09 57–10 12	RB → Cn and temporarily strengthening to 3 at 10.00 and 10.02.	2 to 3
	Semi-corona at 09.57.	
10 12–10 28	HA → DS → 0, and R tufts.	0 +
August 24.		
h m h m		
05 13–06 07	R and RB mainly in E. and NE. sky.	1
06 08–06 29	Multiple arc system overhead. (RA or D seen from below.) Becoming temporarily strong in parts (moves NS. transverse to its own length, 06.19–21).	2 to 3
06 29–07 11	Arc system overhead remains in position with spasmodic movements N. and S. as if pivoted about E. and W. horizon points; definite R structure at times; mainly in or to S. of M.P.V.	2
07 11–08 22	Arc system overhead persists with movements to N. and S.; at times bright (07.17 intensity 3).	Mainly 1 to 2
	At times degenerates to DS.	
08 22–09 41	HB, RB, and DS generally weak and diffuse.	1
	Features: Only prominent feature of this display was persistence of arc system overhead, moving N. and then S. Probably persistent D or RA seen from below. No really active Cn or D periods.	
August 25.		
h m h m		
04 35–06 16	Extensive multiple arc system across N. sky. Gradually increasing elevation (bright, at times 3).	Mainly 1 to 2
ca. 06 16	Arc system moved through zenith into high S. sky.	1
06 16–06 47	RA and HB systems across both N. and S. sky converging at E. and W. points of M.P.V.; mainly moderate intensity; no violent movements or colouration.	2
06 48	R in E. sky, strengthening and extending to zenith.	3
06 48–06 57	R in E. → RB → Cn, with much red colouration and violent movement.	3 +
	Mainly in NE. sky but extending to zenith.	
06 58–07 08	Strong Cn activity continued in overhead and N. sky; much movement and colouration: intensity 4 at times.	Mainly 3
	Tendency to Corona 07.07.	
07 09–08 10	RA across N. sky; disintegrating to RB and R at times.	Mainly 2
	Glow over most S. sky, continues for one hour till 08.10, gradually retreating to S. horizon to form very diffuse arc there.	1
08 10–08 27	RB and R continue in N.	1 to 2
08 27–08 41	RB in N., → bright Cn with much movement.	At times 3
08 41–08 57	HA from glow continues across S. sky; Cns in N. degenerating to RB and diffuse R patches, gradually disseminating over all overhead and middle sky.	2
08 58–09 00	RB in N., again temporary Cn, but weak and very transient.	Momentarily 3

Brief Summary of Auroral Notes (contd.)

August 25—*ctd.* h m h m		Average Intensity.
09 00–10 15	HA (from glow at 07.09–08.10) across S. sky, persisting quietly, gradually weakening.	1 to 0+
	In N., R and RB activity mainly moderate but tendency to Cn formation at times (*e.g.* 09.39–42).	
August 26. h m h m		
04 59–05 47	RB and RA in E. and SE. sky, rather diffuse and weak: tending to form Cn, 05.23 and 05.35, when intensity 2 to 3.	1 to 2
05 48–05 52	RB rapidly forms D and Cn and converges to zenith; much rapid movement: tendency to Corona at 05.48, and actual Corona at 05.50.	3
05 52–05 57	R masses in upper sky.	1 to 2
05 58–06 06	Fresh Cn and D formations overhead, covering all upper sky: tendency to Coronas 05.58 and 06.01.	3+
06 06–06 08	RB and R.	1
06 09–06 15	RB in NE. sky → Cn; temporary activity quickly waning.	1 → 3 → 1
06 15–06 48	Long multiple RA system overhead along M.P.V.	2
06 49–07 00	RA and RB systems overhead; degenerating to DS; all R structures poor.	1+
07 02–08 28	Multiple RA emanating from E. end of M.P.V. across both N. and S. sky and converging again in W.; mainly moderate intensity.	2
	Tendency to Cns with wave movement, brightening at times to 3 or 3+, *e.g.* 07.06, 07.48, and 08.03–15 intermittently.	
08 28–09 01	RA across middle S. sky.	1
	Glow in S., converging to low HA across S. horizon.	0+
09 03–09 46	Lull.	
09 46–10 02	Irregular R and RB patches in middle and upper sky formed fleeting Cn at 09.51, when 3.	1 to 2
	Features: A moderate display, chiefly of RA and RB forms, starting in the E. sky immediately after sunset and rapidly extending towards W. with diminishing twilight.	
August 27. h m h m		
04 22–05 30	RB and R patches in E. and ENE. sky; mainly bright.	2+
05 30–06 40	Activity continuing strongly behind cloud over most of sky.	
06 40–06 50	RB in E. becoming Cn; wave movements along length of Cn.	3 → 1
06 50–07 36	RA and Cn activity continues strongly, both in N. and S. sky and overhead. Cloudy.	2 to 3
07 36–07 56	Strong Cn activity continues mainly in SE. but also in N. sky.	3
07 57–08 03	Cn across S. sky → D, extremely bright, strong colouration.	4
	Coronas at 07.59.00, 08.00.26, and 08.00.45. Recurrent waves of R and D formations forming C. Continuing largely obscured by cloud.	
08 03–08 11	Further very strong Cn activity with much rotatory motion and wave movement; brilliant colouration.	3 to 4
	Tendency to Corona at 08.06.25, and complete Corona at 08.09.10. Tendency to triple Corona at 08.10.30.	
08 11	All S. sky covered with strong long R and also through zenith into N. sky partly; parallel with M.P.V.	3
08 11–08 54	RA, RB, and Cn activity continuing over most sky, especially overhead; mainly strong with much wave movement and colouration at times. Tendency to Corona: 08.11.38, 08.35.10, and Corona at 08.50.50.	3
	At times brilliant colouration and violent movement, *e.g.* 08.16 and 08.47–50.	4
	Periods of reduced activity: *e.g.* 08.37.	
08 55–10 05	Intermittent Cn, RB, and R activity.	1 to 2
	Features: Display characterised by continuity of very strong activity though almost continuously veiled by cloud.	
August 28. h m h m		
	All early part of display obscured by cloud 9+/10 decreasing to 5/10 by 06.20, then 9+/10 in latter half again.	
05 25–05 35	Luminosity SE. extending over whole sky.	2

Brief Summary of Auroral Notes (contd.)

August 28—*ctd.*		
h m h m		Average Intensity.
05 35–06 02	Intense RB, Cn, and D activity in S., E., and overhead sky.	3 to 4
	Semi-corona 05.43.42. Coronas at 05.45.00, 05.45.45, and 05.50.20.	3 +, 4
	Much wave movement in Cn and D, and colouration in Coronas; activity overhead.	
06 02–07 10	Moderate activity over whole sky. RA, RB, and irregular R in N. Strong glow in S. with R structure superposed at first, then → HA over S. horizon.	1 to 2 +
	At 07.03 near end of this phase RA in N. → Cn with rapid wave movements; quickly waned.	Temporarily 3
07 11–07 16	Second wave strong activity, RA round middle sky → Cn → D. With Corona at 07.13.50.	3 +
07 16–07 25	Sky covered with diffuse R structure; at 07.20 border formed on luminosity in NW. and slowly swept across sky towards SE. leaving sky completely clear to N.	2
07 26–07 41	Fresh R → RA → Cn, then dissociated in N.; very transient.	1 to 2
07 42	Tendency to weak and vague Corona from multiple RA overhead.	1
07 43–09 09	Frequent and intermittent waves of strong Cn and RB activity behind cloud at times; very strongly coloured and active formations, generally quickly subsiding and being replaced by fresh outbursts.	3
	Tendency to Coronas: 07.42.35 (much rotation), 07.48.35, 08.00.15, 08.01.53 to 08.02.15, 08.05.25, 08.18.20, 08.46.08, 09.10.15.	
	Period of most continuously strong (3 +) activity 08.32–09.02, especially 08.45 and 08.55.	3 to 4
09 09–10 15	RA and RB in NW.–SW. sky mainly.	1 to 2
	Features: Display characterised by frequent outbursts of activity culminating in weak Coronas or tendencies to Coronas; outbursts usually waning quickly and starting again from fresh RB.	
August 29.	Continuously overcast sky; no aurora seen.	
August 30.		
h m h m		
04 32–06 38	Activity practically confined to N. sky, except from 04.52 for short time when overhead RA from N. moved slowly into upper S. sky and disintegrated.	
04 32–04 37	HA in N.	1 to 2
04 37–04 43	HA → RA.	2
04 44–04 51	RA from HA → D → RB.	1 → 3 + → 1
04 52–04 54	RA overhead moved into S. sky, disintegrating.	1 +
04 54–05 02	R in W. → D mounting to zenith and converging as vague Corona at 04.56.53; much Cn activity overhead and in N. sky then becoming diffuse.	2 to 3
05 03–06 38	Arc and band formations across N. and overhead sky; at times covering whole N. sky. Sky mainly veiled by cloud.	0 +, 2
06 39	Activity moved into S. sky from N.	
06 40–07 17	All upper and middle sky active (weak to moderate) with R, RB, and at times Cn formations; strong glow continuing across S. sky, gradually converging to arc formation.	1, 2
07 17	All activity confined to S. sky.	
07 18–07 21	RA in SE. → Cn → D and Corona with violent movements and strong colouration.	4
	Corona (very fleeting) 07.21.33.	
07 21–07 32	Violent activity subsided; whole S. and E. sky covered with R and Cn.	2
07 34–07 39	Fresh burst violent Cn and D activity with high colouration and much movement.	4
	Fleeting Corona 07.37.22, quickly spread out into D along M.P.V.	
07 39–07 43	Glow over SE.; RB and R elsewhere.	1 to 2
07 45–07 49	Further burst very strong Cn and D activity.	4
	Corona 07.46.23 quickly extending along M.P.V. as D. Corona 07.47.33.	
07 50	All activity confined to S. sky.	

August 30—*ctd.* *Brief Summary of Auroral Notes* (contd.)

h m h m		Average Intensity.
07 51–07 57	Fresh outburst D activity from overhead RA, violent motion and purple colouration; D completely purple-red. Changes of colouration from red to green and *vice versa*.	4
07 58–08 27	Whole sky full of diffuse R and G. At times D formed out of R to form incomplete Corona 08.07.33.	1 to 2
08 27–10 00	Activity continues behind cloud; no details.	
August 31.	Continuously overcast.	
Sept. 1.		
h m h m		
04 45–10 00	Activity probably continuous, but with persistently overcast sky; forms not discernible except during the period 04.52 to 05.20 when arcs and bands were mainly confined to N. sky.	
Sept. 2.	Sky overcast throughout night.	
Sept. 3.		
h m h m		
04 45–04 55	Faint HA across NE., veiled by cloud. Sky thereafter became overcast and remained so throughout the night.	
Sept. 4.		
h m h m		
04 55–09 30	Activity more or less continuous, but no details owing to cloud.	
Sept. 5.		
h m h m		
04 58–06 28	Broken arc formation from SE. or E. horizon to overhead, then into NW. sky; arc (apparently HA at times) remaining steady and quiet, then breaking into diffuse RB; reforming HA again and so on; most HA formation primarily overhead; generally weak.	
06 29–06 56	Probably RA and Cn formations from SE. to NW.; incomplete notes, photography in progress.	At times 2 to 3
06 56–07 02	RA, R, and Cn in S. sky; mainly extending SE. to NW.	
07 02–07 11	Probably bright Cns. Observations again interrupted by photography.	
07 13–07 50	RA overhead. R tufts mainly moving from S. to N. sky.	Occasionally 3
07 53–08 06	HA (or RA) from SE. to NW. becomes steadily more active; becoming long RB and R → Cn.	3
08 06–08 07	Bright Cns from SE. to overhead, thence into NW.; quick WE. movements.	4
	Corona at 08.07.47.	4
08 08–09 11	Much Cn activity overhead; violent movements (WE. but also to-and-fro) along Cns; brilliant colouration, continuously active.	2 + to 4
09 10–10 06	Details of activity obscured behind cloud.	
Sept. 6.		
h m h m		
03 50–04 48	Quiet weak partial HA, sometimes multiple; generally in E. and overhead sky approximately along M.P.V.	
04 48	HA disintegrates into R.	
04 48–04 55	HA multiple from E. sky to overhead along M.P.V.	
04 55–05 03	R appearing in N. sky, and then RA and R overhead and along M.P.V.	
05 01–06 01	(at least). All activity confined to S. sky. During this period RA dispersing and reforming along M.P.V., sometimes intensity 2 or 2 +. Mainly in E. half of sky, but in and to S. of M.P.V.	1, 2
06 01–06 23	Long R, RB, and partial RA continuing, especially narrow RA (sometimes described as HA, therefore must have been quiet) across low S. sky.	1 to 2
06 24–06 48	Much Cn activity with violent movements, mainly in S. sky till 06.39, then whole sky filled with Cn and D activity.	3 to 4

Sept. 6—*ctd.* *Brief Summary of Auroral Notes* (contd.)

h m h m		Average Intensity.
06 24–06 48	Coronas wholly or partially complete 06.36.20, 06.40.31, 06.44.22. From note at 06.49, quiet HA apparently persisted during whole time of violent activity.	
06 48–07 13	Active RB and R in E. and overhead sky.	
07 13–08 02	Almost continuously active, Cns, D, and Corona at times filling whole sky. Coronas at 07.15.46, 07.16.31, 07.18.56, and 07.35.41. At times brilliant colouration and much agitation, *e.g.* 07.30 and 07.34. During this period, though activity overhead and in S., more persistent arc formations across N. sky.	
08 02–10 21	While narrow HA persists across S. sky, many other R, RB, and RA (broken) formations mainly in S. sky and from E. and W. horizons.	

Sept. 7.

h m h m		
04 26–05 13	HA at first across N. sky, gradually becomes higher, passes through overhead at 04.59 and down into S. sky.	
05 13–05 16	HA → RA and increases brightness (3) and disintegrates to R.	
05 16–05 26	HA in S. sky reformed and disintegrated twice; very bright and active R, 06.24 in E. sky.	2 to 3
05 27–05 31	Violent Cn movements SE. to SW. in high S. and overhead sky. Corona at 05.28.51.	3+
05 31–05 40	Cn activity passed through overhead into N. sky; continuously strong with much to-and-fro movement.	
05 43–05 59	Cns replaced by single RA (from E. to W.) across overhead sky, gradually falling back into S. sky.	2
05 59–06 07	RA becoming R, D, and Cns with much violent movement and brilliant colouration: invading N. sky again.	3 to 4
06 08–10 26	RA intermittently persists across N. sky and from NW. horizon throughout rest of evening; at times breaking into RB and Cns (*e.g.* 07.21–26, 08.17–21, 08.52–54, 10.10 when strengthening to 2+ or 3).	

Sept. 8.

h m h m		
	Whole display marred by veil of cloud but probably intermittently very active.	
03 18–07 00	Active periods 03.20–35, 04.40–05.20, 05.40–50, 06.10–07.00, and all mainly in high N. or overhead sky. At 07.00 very active WE. movements.	
07 10–07 16	Circulating RA overhead.	1, 2
07 17–07 24	RA weakened.	
07 27–07 34	Strong activity along M.P.V. and in overhead sky.	3
07 35–07 50	Activity mainly in S. sky. Corona at 07.50.49.	
07 50–08 02	Strong Cn activity followed Corona mainly in high N. and overhead sky.	
08 03–08 15	Again bright RA and RB in N. sky.	
08 16	Activity moved from overhead into S. sky.	
08 22–08 31	RA formed along M.P.V. and moved into S. sky.	
08 32–09 00	Weak RA along M.P.V. or N. sky.	
09 04–09 06	Cn in high S. developed from RA; then disappeared (09.06).	
09 06	New Cns in N. sky.	
09 06–09 18	RA formation across N. sky.	
09 18–09 20	RA → Cn with violent W. to E. movements and moved into S. sky.	3
09 21–09 22	Cn → RB → DS.	
09 22–10 00	Spasmodic RA activity.	

Sept. 9.

h m h m		
04 00–07 20	Continuously cloudy, but aurora at times very intense; no details.	
07 00–07 47	RA activity at times becoming Cn with long R filling whole NW. and N. sky.	2 to 3
07 47–07 49	HA across S. sky → RA → RB.	Temporarily 3

Brief Summary of Auroral Notes (contd.)

Time	Notes	Average Intensity.
Sept. 9—*ctd.*		
h m h m		
07 49–07 53	RA across high N. and overhead sky, moving into S., then steady.	
07 53–08 04	Overhead activity R, RB continuous; RA continues across N. sky and HA $\rightleftharpoons$ RA across S. sky.	
08 04–08 08	Cn and D activity overhead. Corona (?) at 08.04.54, and incomplete Corona at 08.07.27.	
08 09–08 35	RA, R, RB activity continues round middle and overhead sky; HA (multiple at times) continues across S. sky.	
08 39–09 02	RA continues round middle S. sky, and broad arc (probably diffuse RA) along M.P.V. through overhead.	
09 02–09 10	Apparently little or no activity.	
09 12–09 27	RA across S. sky strengthening and extending overhead.	3
09 27–09 38	RA $\rightarrow$ Cns $\rightarrow$ R $\rightarrow$ D, much to-and-fro movement, and colouration overhead. Probably Corona at 09.36.39.	
09 38–10 10	RA and R in NE., SE., and overhead sky; becomes Cn with much movement at times, *e.g.* 09.39–53 and 10.05.	
10 12–10 34	R in N. sky (E. and W.), mainly weak; quiet HA continues across S. sky.	1
Sept. 10.		
h m h m		
04 00–08 41	Spasmodic HA and RA mainly weak. No activity at 08.30.	1
08 41–08 58	RA, at first NW.–SW., extending across S. sky $\rightarrow$ Cn with violent wave and ray movements, all in S. sky.	3+
09 02–09 20	Much Cn and D activity with violent movements and colouration; mainly in high S. and overhead sky; in NW. sky at 09.17. Coronas at 09.09.19, 09.12.32, and 09.18.21; at times whole upper sky (N. and S.) filled with D.	4
09 20–10 10	More or less continuous activity. Coronas noted at 09.35.29, 09.55.07, 09.56.39, 10.03.29, and 10.03.59. Glow continued across S. sky, with weak clear-cut HA border at times. First mentioned at 09.19, still present at 10.16, continuing at end of this display, 10.35; this persisted throughout D and Cn activity in high S., overhead, and N. sky.	3, 4
10 10–10 35	Feeble RA and R.	1
Sept. 11.	Luminosity through cloud. Continuously overcast.	
Sept. 12.	Sky completely overcast throughout night.	
Sept. 13.		
h m h m		
03 50–06 30	HA across middle N. sky; moving bodily S.; at times double; always feeble. Occasional weak R structure.	0+ to 1
06 30–06 42	RA across S. sky.	1 to 1+
06 44	RA brightened; rapid extension, colouration, and drift of R in RA from E. to W.	2+
06 46–06 55	RA across sky; at first double then splitting; increasing altitude and becoming irregular.	2
06 55–06 57	RA $\rightarrow$ Cn; extends quickly upwards.	Temporarily 3
07 00–07 02½	RA across S. rapidly increasing in intensity, $\rightarrow$ RB $\rightarrow$ Cn with much violent movement; brilliant emerald green colouration.	3+ to 4
07 02½–07 07	Much D activity with violent movement. Possibly Corona at 07.02.51.	3+ to 4
07 09–07 36	RA and R masses largely in N. sky, but also overhead (3 at 07.28).	Mainly 1 to 2
07 37–07 46	RA $\rightarrow$ Cn $\rightarrow$ Corona (07.46.46).	2
07 46–07 55	Probably much Cn and D activity and quick movement (C at times).	3+
07 55–08 16	RA and RB in N. sky.	1 to 2
08 16–08 45	No note of activity.	
08 45–09 00	Arc almost overhead, probably really very diffuse RA. 08.48.00–09.00.30 RA overhead or in high N. sky.	2
09 01–09 05	Rapid development RA $\rightarrow$ Cn and D; very bright (purple patches 09.01.35), much movement. 09.03–04 purple Corona with rotatory movements.	4
09 06	D rapidly waned.	1

Brief Summary of Auroral Notes (contd.)

Sept. 13—*ctd.* h m h m		Average Intensity.
09 07–09 15	Spasmodic RA activity.	1 to 2
09 16	All activity subsided temporarily.	
09 19–09 38	RA, RB, and R.	1 to 2
09 39	RB → Cn; elliptical formation.	2 +
09 40–09 53	RA and RB.	
Sept. 14.	Sky overcast throughout dark period.	
Sept. 15. h m h m		
05 50–07 00	HA across S. sky; at times disintegrating into HB.	Mainly 1
07 04	No activity.	
07 08–07 18	RA in SE. rapidly developed to Cn and D; much colouration and agitation (Corona 07.12.42).	4
07 19–07 55	Residual D and Cn waning with fresh RA and RB in W.	1 to 2
07 56–08 04	Very active interval; D developing from RA in SE. (possibly C, but no details owing to photography).	4
08 05–08 12	Rapid waning of all activity.	1
08 13–08 26	Lull (no activity at 08.21).	
08 26–08 54	R(or H?)B.	1 to 2
08 55–08 57	Temporary intensification of elliptical RB.	3
08 58–10 23	Poor activity continuous; degenerated to mere glow at times over N. sky. Occasionally, *e.g.* near end at 10.20, transitory enlivening (2 +) of RA to Cn with wave.	1 to 2
Sept. 16. h m h m		
08 00–08 16	Feeble HA with spasmodic tendency to R structure.	
08 16–10 15	No activity.	
	Whole night remarkable for its negligible activity compared with September 15 and 17.	
Sept. 17. h m h m		
05 20–06 12	HA extending from SE. sky; mainly diffuse; double at times; R patches.	2
06 12	HA gone; no other activity.	
06 14–06 28	HA reappeared → RA; RB → R bundles.	1 to 2
06 28–06 37	RB and R → Cn with much movement overhead. Coronas 06.29.55 and 06.31.15.	3
	Details lacking owing to photography.	
06 39–07 13	RA, RB, and R patches.	1 to 2
07 28–07 34	Cn and D overhead, very active and much coloured. Corona 07.29.36.	4
07 35–07 52	RA partial and double.	1 +
07 53–08 01	RA → Cn.	3
08 02–10 32	Continuously active, but in undistinguished way. 08.45 RA or Cn with wave movements and increased intensity: also at 08.51, 08.54–58, 09.00, and 09.17.	1, 2 2 + to 3

ATMOSPHERIC ELECTRICITY

By P. A. Sheppard, B.Sc.

1. INTRODUCTION

The systematic observations in atmospheric electricity were devoted to potential gradient, air-earth current, conductivity, and small ion content. In the case of potential gradient continuous autographic registration was employed; the other elements were observed each morning and afternoon when conditions were favourable. The number of condensation nuclei was also measured.

In addition, measurements were made of the rate of production of ionisation in a closed vessel, and a special investigation was undertaken of the diurnal variation of this quantity and of conductivity, air-earth current, and small ion content by means of the eye-reading instruments.

2. METHODS OF OBSERVATION

I. *Potential gradient.*—The records of potential gradient were obtained from a Benndorf electrograph installed in the south corner of the meteorological observatory hut, which was of log construction.

The collector rod passed through a hole in the south-east wall, distant 30 cm. from the south corner, and projected 38 cm. from the wall until 1933 January 14, when the length was increased to 101 cm., at which it remained fixed until 1933 August 31, the end of the period of measurement. The collector was 184 cm. above the ground, which was of a rather uneven nature. There was a tendency during the winter for snow to collect in drifts in the neighbourhood of the hut, but such drifts were immediately cleared from the south-east side of the hut on the abatement of successive wind- or snow-storms, so that a sensibly constant exposure of the collector was maintained.

On the inside of the hut the collector rod passed through a small hole in one end of a wooden box, where it was supported horizontally on two rods embedded in sulphur. The earthed metal cases surrounding the sulphur insulators were wound with resistance wire so that a heating current could be circulated on occasions when the insulation was liable to deterioration. Such occasions were very few and were confined to the summer months.

A wire passed from the collector rod to the terminal on the electrograph casing connecting to the electrometer needle, and the quadrants of the electrometer were maintained at suitable potentials by means of dry batteries.

Polonium was used as the radioactive material for the collector, and was deposited on copper rods about 4 cm. long and 0·5 cm. diameter. In order to maintain an approximately steady activity of the collector, the number of polonium-coated rods in use was increased from one to four during the year to allow for the decay with time of the polonium activity. A number of tests were made during the year of the rate of pick-up of potential by the whole electrograph system, and the time taken to reach half the final value of potential in no case exceeded a few seconds. Since the insulation was maintained at very high values save for occasional short lapses, the recorded and actual potentials at the collector were in effect coincident. This was not the case, however, during rapidly varying fields, when the inertia of the moving system was too great to allow it accurately to follow the voltage changes.

Daily tests of the insulation of the electrograph were made by removing the collector and charging the system to some voltage measured by means of a Wulf bifilar electrometer in combination with the system, and the fall in voltage over a measured period was directly observed. Simultaneously the scale value of the electrograph was obtained. Zero or "earth" marks were made at the beginning, middle, and end of each day's trace.

To obtain a reduction factor for converting the voltage recorded by the electrograph to the potential gradient over a level surface, the Simpson stretched wire method was adopted. An insulated wire was stretched horizontally between two metal posts, 10·5 metres apart, which were cemented to the granite rock at a relatively flat portion of the island. At the centre of the wire a polonium collector was fixed at exactly 1 metre above the ground. (Two collectors were used during the latter portion of the year.) One end of the wire was connected to a Wulf bifilar electrometer, 6 metres from the post, and twenty to forty half-minute readings of the electrometer were taken during each experiment. The reduction factor was then obtained from the mean of these readings and the corresponding mean potential recorded by the electrograph. Such observations were taken as frequently as time and weather permitted—on the average ten per month.

The site of the above observations was a partial eminence some 4 or 5 metres above the level of the lake which half surrounded the site at an average distance of about 100 metres. Consequently the values of potential gradient as given may be slightly greater than over a more extended flat surface, but not by more than a very few per cent.

The maximum field strength which could be recorded was normally ± 550 volts per metre. On occasions when the field was large and disturbed, some attempt was made to increase the range of recordable voltage by decreasing the sensitivity of the electrometer, but very little extra information was obtained thereby.

Mean hourly values, centred at the exact half-hours, are tabulated from the curves for the potential gradient expressed in volts per metre over a level surface (Tables 271–283, Vol. II). Greenwich mean time (G.M.T.) is used for the tabulations, and indeed for all the atmospheric electrical data. This differs from zonal mean time —the time of the nearest hourly meridian of longitude, viz. 120° W.—by 8 hours. An indication is made in the tabulations of the zonal time for certain Greenwich hours.

The key to the tabulations is placed at the head of the tables. Where blanks occur in the tabulations the record has been defective or missing. Such occasions are particularly frequent during December and January, when considerable trouble was experienced with the electrograph. The trace at this time became very lifeless, and difficulty was found in getting consistent earth marks and scale values. The trouble was located in two places. Owing to the exceptional dryness of the air in the observatory hut during the winter months, high static charges were acquired by normally poor insulating surfaces, in particular by the paper on which the record is made, and by the glass dash-pot containing sulphuric acid through which the collector voltage is led to the electrometer needle. These charges influenced the motion of the moving parts of the electrometer, and so a spurious trace was obtained. To overcome these troubles the electrometer needle boom was screened from the influence of any charge on the recording paper by interposing between the boom and paper a sheet of thin tin-foil connected to earth, and the glass dash-pot was replaced by a metal dish in which glycerine was used instead of sulphuric acid. The damping vane of the electrometer was appropriately reduced in size at the time of the latter change. No further trouble was afterwards experienced with the electrograph.

II. *Air-earth current and conductivity.*—Observations of the air-earth current and positive polar conductivity were made on days of fine weather conditions at approximately 16h 30m and 22h 30m G.M.T. (8h 30m and 14h 30m Z.M.T.).

The site of the observations was about 15 metres to the north of the observatory hut, and near the top of a slight mound of granite rock rising some 5 metres above lake-level. It was, unfortunately, impossible to choose a site free at all times from smoke passing over it from huts in the settlement, and many observations were obviously affected by this source of disturbance of the atmospheric electrical elements.

The apparatus used * was a modification of C. T. R. Wilson's universal electrometer, and consisted of an insulated test-plate connected to a Lindemann electrometer and compensating condenser. When the apparatus is set up in the open, an instantaneous exposure of the test-plate produces an induced charge on the plate proportional to the field above it; when the plate remains exposed and at earth potential (by an adjustment of the compensating condenser) for a certain time, the plate receives a charge from the ionic current flowing from the air to the plate under the action of the field. The positive polar conductivity can then be deduced by dividing the current flowing into the plate by the electric field over the plate (the field, of fine weather type, being positive).

In order to obtain a uniform field over the test-plate and to prevent a variable distortion of the field by the presence of the observer, the test-plate was surrounded by a large guard ring, 1 metre square, supported on adjustable legs approximately 1 metre in length. The observer's body during attention to the instrument was beneath the guard ring. With this arrangement the field over the plate was approximately twice as great as over the site of the absolute observations of potential gradient, and on this account the measured current was greater than that over an extended level surface. The tabulated values of air-earth current were therefore obtained by multiplying the conductivity by the field as measured by the electrograph during the period of the observations.

The experimental procedure was as follows. A field measurement was first made and then followed by four or five minutes' exposure of the test-plate to the air-earth current. A further field measurement was then made and the mean of the two used as the mean field during the period of exposure. This procedure was in general repeated four times to give mean values of conductivity and air-earth current during 20 to 25 minutes.

The times at which the observations were made were determined by a preliminary investigation of the approximate variation of the two elements between 8h and 20h Z.M.T. in July 1932. These results seemed to indicate that conductivity decreased steadily from 8h to about 15h and then increased. 8h 30m and 14h 30m Z.M.T. were accordingly chosen as the standard hours of observation. A further investigation of the diurnal variation was made in the summer of 1933.

Some difficulty was experienced in the measurements during the winter months. In the first place, observations were generally limited to those occasions when the wind was below about 6 to 7 metres per second, since drift snow set in on most occasions when the wind rose above this value and produced a very disturbed potential gradient. Poorness of light during December and January frequently made observations difficult at that time. Also smoke was naturally a greater nuisance during the winter than at other times, and frequently caused suspension of the observations. A further source of trouble during the cold period was an apparent charging up of the electrometer due to a piezo-electric effect in the amber insulation of the instrument, and this was not immediately noticed. It was overcome by leaving the instrument in the open air for a considerable time before use until it had reached a steady temperature, when the trouble disappeared. Observations affected in the above manner have of course been eliminated.

* P. A. Sheppard, *J. Sci. Instr.*, 9, 8, 1932.

For the above reason the winter observations are rather few in number compared with those obtained at other seasons.

III. *Concentration of small ions.*—The concentration of positive and negative small ions was measured by means of a modified Ebert ion counter.* The new instrument differed from the original in that the central cylindrical electrode was connected to a Lindemann electrometer, and prior to an observation was earthed and then insulated. The field driving ions to the electrode was obtained by charging the surrounding cylinder to a fixed potential sufficient to produce saturation of small ions for the particular speed of aspiration of air obtained with the motor-driven fan. An earthed cylinder surrounded the charged cylinder, and the design of condenser mouth was that adopted by Swann † in a similar modification to the Ebert ion counter. This mouth removed any "turning-back" effect which the ions might experience on approaching the charged condenser from the outer air. The instrument had marked advantages over the standard Ebert instrument, for reliable observations of ion content could be made in about four minutes, and insulation losses were much less serious than in the original instrument.

The observations were made simultaneously with those of air-earth current and conductivity. The apparatus was mounted on a bracket extending from the north-west wall of the observatory hut. An earthed canopy was placed 1 metre above the bracket so that the region near the mouth of the condenser should be relatively field free.

Since only one instrument was available the following observational procedure was adopted. The concentration of positive ions, say, was measured for about four minutes by aspirating 200 litres of air through the condenser. In a further similar period the concentration of negative ions was obtained by reversing the sign of charge on the outer cylinder. This procedure was then repeated so that two estimates of both positive and negative ion concentration were made over the same period as the conductivity and air-earth current experiments. Insulation tests were made at the end of observations, and corrections applied when necessary.

IV. *Condensation nuclei.*—A rather incomplete series of observations was made of the concentration of condensation nuclei by means of a Casella pattern Aitken nucleus counter. The observations were made concurrently with the electrical observations at 16h 30m and 22h 30m G.M.T. (8h 30m and 14h 30m Z.M.T.), but the series is incomplete partly on account of an accident to the instrument in the summer of 1932. The damage was repaired, but winter observations are very few on account of the unsatisfactory functioning of the instrument in very low temperatures. Various methods of working were tried but none proved very satisfactory.

The dilution markings on the pump barrel of the instrument were wrong, but in the working up of the results a correction has been applied.

V. *Rate of production of small ions in the atmosphere.*—An attempt was made to measure the rate of production of small ions in the atmosphere by a modification * to the conductivity and air-earth current apparatus. The test-plate of the apparatus was replaced by a long brass electrode which was surrounded by a cylindrical zinc can of 19·5 litres capacity. The can was mounted and insulated by means of an ebonite collar attached to the earthed tube surrounding the electrode at its base. A voltage was applied to the cylinder sufficient to produce a saturation current of small ions between the cylinder and electrode.

This apparatus was set up on the rock at the site of conductivity observations and the current in the ionisation chamber measured. The sensitivity was such that an accurate reading could be obtained in one minute; but to overcome variations occurring from minute to minute, several observations were taken at any one time to arrive at a reliable mean value. The ionisation current is due to ions formed inside the chamber by the following ionising radiations:—

* P. A. Sheppard, *loc. cit.*

† W. F. G. Swann *Terr. Mag.*, 19, 4, 1914.

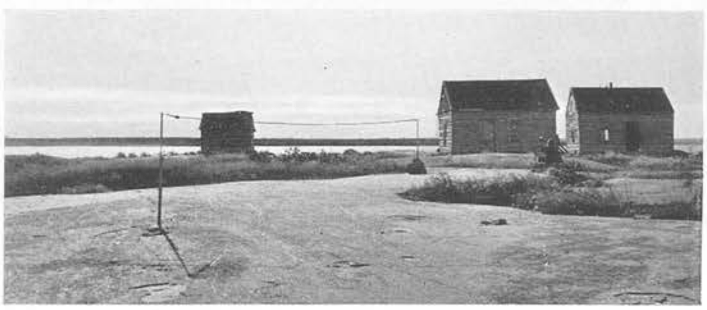
PLATE V

(*a*) Sheppard with his modified Ebert small ion counter at site of observations.

(*b*) Collector used with Benndorf electrograph for recording the earth's electric field.

(*c*) Modified Wilson air-earth current and conductivity apparatus on site of measurements.

(*d*) Apparatus for measuring rate of production of small ions in a closed vessel over the rock. Sheppard observing.



(*e*) Site of absolute measurements of potential gradient. The collector is at the middle of the wire with Wulf electrometer behind.

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(1) β- and γ-rays from the rock, producing ionisation J_E.
(2) γ-rays from the air over the rock, producing ionisation J_{A_1}.
(3) α-rays from air inside the chamber, producing ionisation J_{A_2}.
(4) Cosmic radiation, producing ionisation J_C.
(5) Radiation from the walls of the chamber, producing ionisation J_R (residual ionisation).

The first four of the above are the agents mainly responsible for the ionisation in the air near the ground during fine weather. It is necessary to determine J_R separately and to deduct this value from the total ionisation in order to deduce the rate of production of ions in the atmosphere itself. The evaluation of J_R was attempted by making observations with the instrument inside chalk caves, and also by surrounding the instrument with lead, but neither method was successful; a large quantity of flint in the chalk probably upset the former method, and insufficient lead the latter. Finally, only an approximate evaluation of J_R could be made, and this consisted in taking observations with the instrument on the lake at Fort Rae over several feet of ice, but at no great distance from land. This procedure eliminated the greater part of the external radiation, leaving only cosmic radiation and some radiation from the air. By allowing 1·8 J ion pairs/c.c./sec. for cosmic radiation and 0·5 J for air radiation, a mean value of 2·3 J was obtained for the residual ionisation. This latter figure may be too high by 1 J or more, but since no precautions were taken in the construction of the zinc can to give low residual ionisation, and since the correction of 0·5 J given above is unlikely to be too large, the value adopted for the residual ionisation seems reasonable.

To obtain accuracy in the rate of production of ions measurement, the ionisation vessel should be of the "thin-walled" type to allow α-radiation to pass through the walls. Since a zinc ionisation vessel was used, the values obtained are likely to be too low by perhaps a few J.

Observations of the rate of production of ions were made at various times during the year, and in addition an attempt was made to determine the diurnal variation of this element.

3. DISCUSSION

I. *Potential gradient.* (a) *Diurnal variation.*—The mean hourly values of potential gradient, given in Table 1, Vol. II, have been analysed to give the diurnal variation on "quiet" days for each month from August 1932 to August 1933, and for the seasons: winter (November, December, January, February), equinoxes (March, April, September, October), summer (August 1932, May, June, July, August 1933). "Quiet" days are those on which precipitation, fog, snow-drift, and negative values of the gradient did not occur. The results are given in Table 1, together with the mean value on quiet days for each month and season and for the year. Fig. 1 shows the variation graphically.

It will be seen that the variation consists mainly of a 24-hour wave, the minimum occurring at about 4h G.M.T. and the maximum at about 20h G.M.T. This variation is similar to that found by the S.S. *Carnegie* * over the oceans, by Sverdrup † on the *Maud* expedition in the Polar Seas, and for typically Arctic stations. ‡

The diurnal variations for the three seasons have been analysed to give the appropriate Fourier Series.

Winter . . $F = 76 + 18 \sin (15t + 176°) + 5 \sin (30t + 304°) + 1 \sin (45t + 352°) + \ldots$
Equinoxes. . $F = 79 + 19 \sin (15t + 171°) + 5 \sin (30t + 346°) + 0{\cdot}5 \sin (45t + 272°) + \ldots$
Summer . . $F = 93 + 7 \sin (15t + 137°) + 6 \sin (30t + 187°) + 1 \sin (45t + 189°) + \ldots$

where t is expressed in hours.

The amplitudes of the 24- and 12-hour waves are approximately constant for

* *Terr. Mag.*, **28**, pp. 61–81 (1923).
† H. U. Sverdrup, *Carnegie Institute, Washington, Pub.*, **175**, 6, pp. 435–460 (1927).
‡ Wien-Harms, *Handbuch der Experimental Physik*, **25**, I, pp. 282–293 (1928).

TABLE I.—POTENTIAL GRADIENT (VOLTS PER METRE) ON QUIET DAYS: DIURNAL VARIATION, MONTHLY AND SEASONAL MEAN VALUES, ADJUSTED FOR NON-CYCLIC CHANGE.

Hour G.M.T.	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24	Mean.
Hour Z.M.T.	16–17				20–21				0–1				4–5				8–9				12–13				
Month and Season.																									
1932 August	107	96	91	78	72	83	93	88	86	85	77	84	89	91	97	92	97	106	119	125	127	129	125	115	98
September	85	78	71	65	68	64	63	65	67	70	67	70	77	82	84	90	89	99	98	105	107	99	95	92	81
October	65	58	53	52	51	55	61	66	69	67	69	73	71	78	87	91	93	91	100	99	98	92	80	70	75
November	63	58	56	57	61	58	59	56	54	59	56	60	66	77	84	81	85	90	93	97	92	86	73	67	70
December	66	65	59	55	58	56	63	65	64	63	67	68	74	82	81	86	95	93	92	100	97	86	77	73	74
1933 January	70	58	59	58	60	57	64	74	68	64	66	71	78	72	66	64	71	76	87	90	90	85	74	72	71
February	89	77	68	68	69	75	73	71	68	72	77	75	81	87	86	97	113	114	105	105	100	98	92	92	85
March	81	75	62	56	52	54	57	61	65	68	74	76	73	81	81	92	85	94	96	99	95	87	86	83	76
April	77	78	73	66	67	67	70	69	67	68	72	71	79	88	93	94	95	97	101	109	102	96	92	86	82
May	83	84	89	82	84	87	84	91	91	83	88	88	89	91	93	96	104	104	107	107	110	99	99	94	93
June	95	91	86	86	80	85	81	87	85	85	85	86	88	87	92	93	98	103	100	107	113	110	108	101	93
July	98	85	79	78	74	76	79	81	91	99	95	98	102	102	101	107	100	102	104	114	114	113	112	100	96
August	90	86	83	75	76	73	76	74	78	75	75	69	73	75	79	84	88	96	114	116	117	113	107	95	87
																						Mean for year			82
Winter	73	66	61	59	61	62	65	66	63	64	67	68	74	80	82	85	94	96	95	100	96	89	80	76	76
Equinoxes	77	72	65	60	60	60	63	65	67	68	71	73	75	82	87	81	92	96	99	104	101	94	89	83	79
Summer	93	87	84	80	77	81	82	85	87	86	86	87	90	91	94	96	98	102	107	112	116	111	109	100	93

winter and equinoxes with a ratio a little more than 3 : 1, but in summer the 12-hour wave assumes almost equal magnitude with the 24-hour wave, which is considerably reduced. This again is consistent with the findings of other workers, *e.g.* at Davos in Switzerland the ratio changes from about 9 : 1 in January to less than 2 : 1 in June. The *Carnegie* results show a similar enhancement of the 12-hour wave in summer. The time of maximum of the 24-hour wave increases from 18·3h in winter to 20·9h in

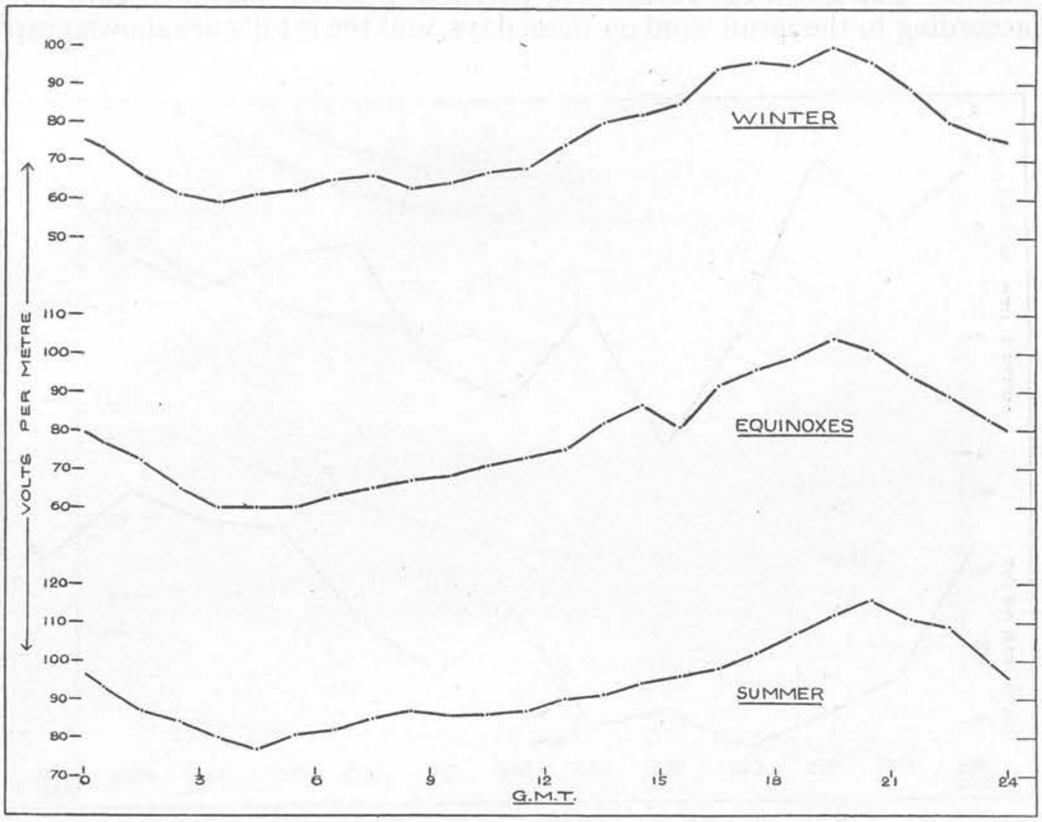

FIG. 1.—Diurnal variation of potential gradient (quiet days) for the seasons: winter, equinoxes, summer.

summer, a similar progression having been observed in the *Carnegie* observations, and by Simpson * at Karasjok in Lapland. The reversal of phase of the 12-hour wave during summer compared with winter and equinoxes is noteworthy. Davos measurements show a rather similar reversal.

Now Whipple † has suggested that the diurnal variation of potential gradient over the oceans and in Arctic regions may be due to the diurnal variation of thunderstorm activity over the earth, and has shown that there is a very considerable sympathy between the diurnal variation curves for the two quantities. It will be of great interest to compare the harmonic components of diurnal variation of potential gradient at Polar Year stations with those for thunderstorm activity over the whole earth for the same period of 1932–33.

(b) *Annual variation.*—The mean value for the year is 82 volts per metre for quiet days, a rather low value compared with many stations, and probably to be attributed to the relatively high electrical conductivity of the air at Rae.

Perhaps more surprising is the well-marked annual variation (Table 1 and fig. 2) which exhibits a minimum in winter (70 and 71 volts per metre in November and January respectively) and a maximum in summer (98 volts per metre in August 1932, and 96 volts per metre in July 1933). This is the reverse of that normally found at stations in the northern hemisphere, but Sverdrup, ‡ whose observations on the

* G. C. Simpson, *Phil. Trans.*, A, 205, 61 (1905).
† F. J. W. Whipple, *Quart. J. R. Met. Soc.*, 55, 1 (1929).
‡ H. U. Sverdrup, *loc. cit.*

Maud extended from November to the following April, found a minimum gradient of 88 volts per metre in November, and a maximum of 118 volts per metre in April. Further, Currie * at the Canadian Polar Year Station at Chesterfield Inlet, Canada, found a minimum value of 60 volts per metre in April, and maxima of 71 volts per metre in June and August, during observations which extended only from April to August. The explanation is probably to be found in the variation of wind velocity with season. The mean daily values of potential gradient on quiet days have been listed according to the mean wind on these days, and the results are shown graphically

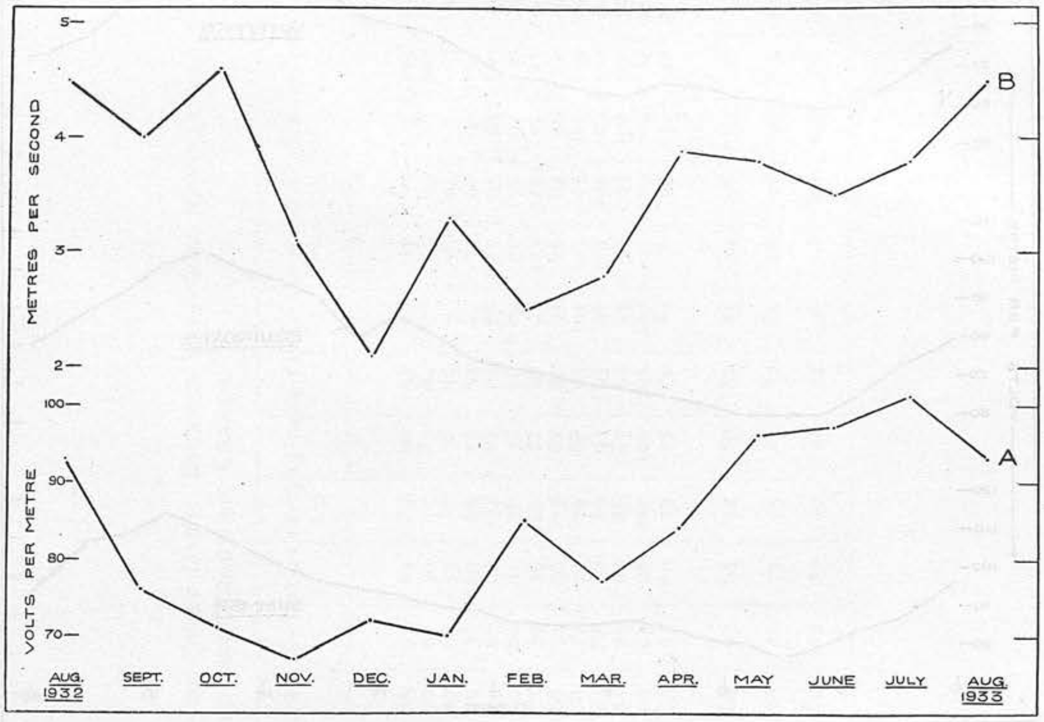

FIG. 2.—A. Annual variation of potential gradient (quiet days); B. Annual variation of wind velocity for the same days.

in fig. 3. It is seen that the gradient increases with wind velocity over the range of winds investigated except at the highest wind, where relatively few observations are obtainable. Now the annual variation of wind for those days used in extracting quiet day potential gradient values is shown in fig. 2, and we see a fairly close parallelism between the potential gradient and wind-velocity curves.

This relationship is to be expected under conditions such as exist at Fort Rae, and at any land station unaffected by relatively local sources of condensation nuclei or large ions. At such places in low winds the conductivity of air near the ground is relatively high, for ion production is a maximum near the ground when only the lower atmospheric levels are considered, and the vertical transport of ions and ion-producing agencies (radium emanation, etc.) is in general a minimum for the lowest winds; and under high-conductivity conditions the field will be a minimum. With increasing winds the vertical transport of ions and ion-producing agencies is increased, the conductivity is lowered and the field increased. Further evidence will be found for this argument when the variation of other electrical elements is considered (3, II (*b*)).

The annual variation of wind velocity at Fort Rae is not necessarily that shown in fig. 2, for when high winds occur during winter the gradient is violently disturbed by the onset of drift snow. Hence days of high wind in winter must be eliminated in determining the behaviour of quiet weather potential gradient, and the average

* B. W. Currie, *Terr. Mag.*, 39, 1, p. 30 (1934).

winter winds tend to be less than average summer winds for the days used in extracting quiet day values of potential gradient.

Atmospheric conductivity and, to a certain extent, therefore the earth's field are determined by the relative concentrations of large ions and small ions. At many land stations the incidence of light winds is coincident with a big increase of large

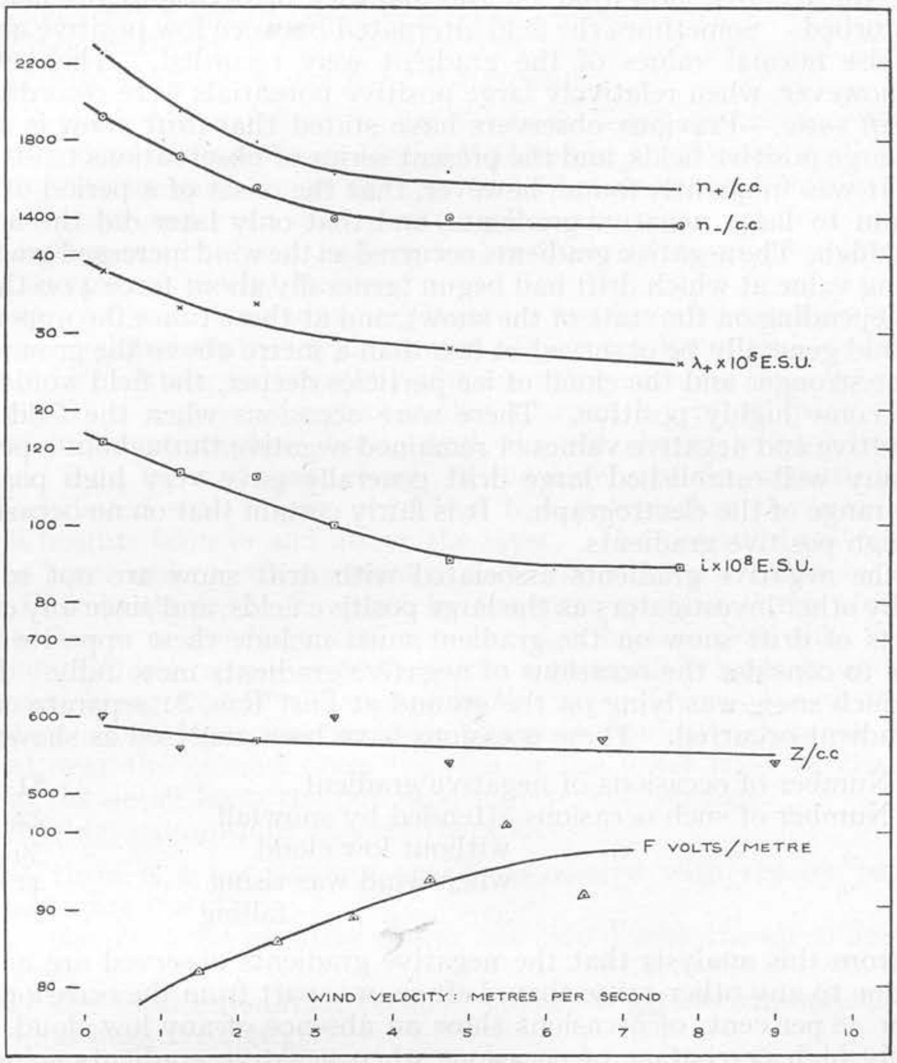

FIG. 3.—Relation between wind velocity and atmospheric electrical elements.

ion content owing to the increased concentration and diminished diffusion of condensation nuclei, which may have their origin at some not very remote distance. Under such conditions the field is increased. At a station such as Fort Rae, however, where, apart from a few local fires, the sources of condensation nuclei are a very great distance away, local winds will not measurably affect the concentration of nuclei (*vide* 3, II (*b*)).

If the above arguments are true, then the diurnal variation of wind velocity will add to the change in gradient which is imposed by the world-wide variation, for the two diurnal curves are approximately in phase for a place with the longitude of Fort Rae.

No relation could be traced between the gradient at Fort Rae and particular wind directions.

(c) *Potential gradient in disturbed weather*. (i) *Snow*.—There were relatively few occasions during the winter of heavy snowfall, and of these only a small percentage were not attended by heavy drift snow. Consequently no definite assertion can be made concerning the sign and magnitude of the field produced by heavy snowfall, but from the records it appears that the field tends to be positive and high. Some occasions were noted, however, when the field alternated in sign between both relatively low and high values.

The occasions of light snowfall were many, and eliminating those attended by drift snow, the records show that on the majority of occasions the field was only slightly disturbed. Sometimes the field alternated between low positive and negative values, or else normal values of the gradient were recorded. There were a few occasions, however, when relatively large positive potentials were recorded.

(ii) *Drift snow*.—Previous observers have stated that drift snow is attended in general by large positive fields, and the present series of observations tends to confirm this view. It was frequently found, however, that the onset of a period of drift snow gave medium to large negative gradients, and that only later did the field become positive and high. The negative gradients occurred as the wind increased gradually from some limiting value at which drift had begun (generally about force 4 on the Beaufort Scale, but depending on the state of the snow), and at these times the upper surface of the drift could generally be observed at less than a metre above the ground. As the wind became stronger and the cloud of ice particles deeper, the field would reverse in sign and become highly positive. There were occasions when the field alternated between positive and negative values or remained negative throughout a period of low drift, but any well-established large drift generally gave very high positive fields beyond the range of the electrograph. It is fairly certain that on no occasion did low drift give high positive gradients.

Since the negative gradients associated with drift snow are not so well substantiated by other investigators as the large positive fields, and since any explanation of the effects of drift snow on the gradient must include these opposite fields, it is worth while to consider the occasions of negative gradients more fully. During the period in which snow was lying on the ground at Fort Rae, 81 separate occasions of negative gradient occurred. These occasions have been analysed as shown below:—

Number of occasions of negative gradient . . .	81
Number of such occasions attended by snowfall . .	22
,, ,, ,, without low cloud . .	39
,, ,, ,, when wind was rising . .	41
,, ,, ,, ,, ,, falling . .	20

It is clear from this analysis that the negative gradients observed are not likely to have been due to any other cause than drift snow, apart from the occasions of actual snowfall, for 48 per cent. of occasions show an absence of any low cloud. Further, the relatively high percentage of occasions when negative gradients coincided with rising or falling winds tends to confirm the observations made at the time that such gradients coincided in general with low surface drift.

One occasion of negative gradient is of particular interest. This was from 11h to 20h G.M.T. on 1933 May 16, when the gradient was steadily negative, except towards the end of the period as the mean value was slowly returning to normal positive values. The gradient was at no time greater than about -500 volts/metre, but it was noticed at the time that no drift snow was present, for the very good reason that almost all snow had disappeared from the ground at Fort Rae. The wind at the time was between 6 and 9 m/s (sufficient to produce drift when snow was lying), and the sky was clear at first and finally contained a variable amount of cirrus. Noticing this unusual combination of circumstances, a special observation of small ion content was made at 19h 18–30m G.M.T., which showed a mean negative space charge in the air due to small ions of 400 ions/c.c. ($1{\cdot}9 \times 10^{-7}$ e.s.u./c.c.). This was towards the end of the period of negative gradient when the field had become -47 volts/metre.

The above instance of negative gradient will be referred to later, as it is of importance in considering the mechanism by which drift gradients are produced. Similar instances in the winter may, and probably did, occur, but passed unnoticed at the time, for low drift was not always obvious, especially in the night hours.

In seeking an explanation of the effects of drift snow on the gradient, we have the following conditions to satisfy therefore:—

(1) Negative gradients associated with low drift, when the top of the drift cloud was visibly below the level of the collector.

(2) Positive gradients, when the drift was heavy and extended to any height greater than a few feet from the ground.

It is first to be noticed that the gradients recorded are means over a certain height interval, derived from the potential V at height h and equal to V/h. Yet it is quite possible that the gradient at the earth's surface or at the collector may be of a very different order and even of opposite sign to the mean gradient under certain distributions of space charge. Failure to bear this in mind may lead to wrong conclusions, as pointed out by McNish.*

Since the gradients demanding explanation are in most cases several times as great as the normal fine weather field, we may neglect the latter and consider only the fields produced by certain distributions of space charge arising from the drift snow.

It is clear from a general argument that distinct layers of space charge must be generated in the atmosphere during drift, the net charge in each layer being of opposite sign; for a layer of space charge of the same sign throughout, however the charge be distributed with height, must lead to a potential of the same sign as the charge at all heights both in and above the layer. The potential will increase with height in the layer and remain constant above. This is readily seen by considering the lines of force in the field. Further, by the same method, if the total numerical charge in the lower of two layers of opposite sign be less than that in the upper layer, the potential will again be of the same sign at all heights in and above the layers, the sign being that of the charge in the upper layer. We shall see that if the lower of two such layers carries more charge numerically than the upper, then the potential near the ground takes the sign of the lower layer of charge, and at some level in the upper layer the potential may reverse its sign.

The following assumptions suggest themselves:—

(1) That there is a net positive charge associated with the ice particles constituting the drift.

(2) That there is a net negative charge associated with the air in and above the drift.

(3) That the total amount of positive charge is greater numerically than the total negative charge.

We shall assume further that the space charge is produced by friction between snow particles themselves or between the drift particles and surface snow, and that space charge is thereby communicated both to the drift particles and to the air in contact with the particles at the time of charge separation, the latter in an ionic form. The vertical mixing produced by wind turbulence will give rise to a vertical distribution of space charge associated with the ice particles, which may be represented, at least approximately, by an exponential formula of the type †

$$\rho_s = \rho_0 e^{-\alpha h},$$

where ρ_s is the space charge at height h, ρ_0 is the value of ρ_s at the surface, and α is a coefficient of fall-off with height. There is both theoretical and experimental support in favour of a formula of this type. The space charge associated with the air, in ionic form, may similarly be represented by the formula

$$\rho_A = -\rho_0' e^{-\beta h},$$

* A. G. McNish, *Terr. Mag.*, 37, 4, pp. 439–446 (1932).

† See W. Schmidt, *Der Massenaustausch in Freier Luft, etc.*, Hamburg, pp. 49–84 (1925).

for which there is indirect experimental evidence. The negative sign indicates that the space charge is negative. We may remark at this stage that the rate of fall-off of space charge ρ_s with height must be much greater than for ρ_A, *i.e.* $\alpha > \beta$, for the snow particles are continually falling by gravitational action, whilst the air ions are relatively unaffected in this way.

We can now derive an expression for the potential V at height h by means of Poisson's law:—

$$\frac{d^2V}{dh^2} = -4\pi\rho.$$

We shall assume that the space charge is uniform horizontally over a distance very great compared with the vertical heights under consideration.

Poisson's equation becomes in the present case

$$\frac{d^2V}{dh^2} = -4\pi(\rho_0 e^{-\alpha h} - \rho_0' e^{-\beta h}), \qquad (1)$$

which gives on integrating once,

$$\frac{dV}{dh} = 4\pi\left(\frac{\rho_0}{\alpha}e^{-\alpha h} - \frac{\rho_0'}{\beta}e^{-\beta h}\right) + \text{constant}. \qquad (2)$$

Now $\left(\frac{dV}{dh}\right)_{h=0} = -4\pi\sigma$, where σ is the density of surface charge, and σ is equal and opposite to the total net charge in the atmosphere above the place under consideration, *i.e.*

$$\sigma = -\int_0^\infty (\rho_0 e^{-\alpha h} - \rho_0' e^{\beta h})dh,$$

or

$$\sigma = -\frac{\rho_0}{\alpha} + \frac{\rho_0'}{\beta}.$$

Applying the boundary condition to equation (2) we obtain

$$\frac{dV}{dh} = 4\pi\left(\frac{\rho_0}{\alpha}e^{-\alpha h} - \frac{\rho_0'}{\beta}e^{-\beta h}\right). \qquad (3)$$

Integrating again, and remembering that V = 0 at $h = 0$, we obtain

$$V = 4\pi\left[\frac{\rho_0}{\alpha^2}(1 - e^{-\alpha h}) - \frac{\rho_0'}{\beta^2}(1 - e^{-\beta h})\right]. \qquad (4)$$

Certain general conclusions may be inferred from equation (4), but it is not possible to arrive at the approximate relative magnitudes of positive and negative charges involved in drift without some knowledge of α and β. Fortunately, we are able to assess values for α and β from various investigations of the distribution with height in the atmosphere of diffusing entities.

Schmidt (*loc. cit.*) gives results of snow-drift densities measured by Wegener at heights of 10 and 180 cm. of 33·4 and 5·7 gm./m.^{3} respectively. Assuming that the drift particles and associated charge are distributed similarly, and that the exponential formula is applicable, we obtain a value of α of about 10^{-2} per cm. In low drift α must be greater than this value, for low drift implies relatively small vertical turbulence which must lead, as Schmidt (*loc. cit.*, p. 64) shows, to greater values of α. A value of 5×10^{-2} per cm. is roughly applicable to low-drift conditions, for when $\alpha = 5 \times 10^{-2}$, ρ/ρ_0 equals 7×10^{-3} at $h = 1$ metre, and 5×10^{-5} at $h = 2$ metres.

β can only be assessed indirectly, for there are neither experimental data on the fall-off with height of ionic space charge produced under drift-snow conditions, nor is there any theoretical formula which may be applied. We shall consider, therefore, the height distribution of other entities which are comparable. These are water-vapour (specific humidity) investigated by Wüst * and Hergesell,† and condensation

* G. Wüst, *Veröff. Inst. f. Meereskunde*, Berlin, Series H, 6 (1920).

† H. Hergesell, *Beitr. zur Physik d. fr. Atmos.*, 8, 87 (1918).

nuclei investigated by Wigand.* Their observations give the following values for the coefficient of fall-off, an exponential formula being assumed:—

Element.	Authority.	Height Coefficient.	Height Interval Considered.
Water-vapour .	Wüst	$1\cdot3\times10^{-4}$ per cm.	2–6 metres
,, ,,	Hergesell	$2\cdot7\times10^{-6}$,,	0–1400 ,,
Nuclei .	Wigand	$1\cdot7\times10^{-5}$,,	0– 900 ,,

Considerable differences are shown, as is to be expected from the nature of the observations, but we can assess β very approximately by means of the above values. We shall assume

$$\beta=10^{-5} \text{ per cm. for thick drift,}$$
$$\beta=5\times10^{-5} \text{ per cm. for low drift.}$$

As in the case of α, we take a higher value for low-drift conditions than for thick drift, though in this case the reasons for the difference are not so obvious as for an entity which possesses a finite velocity of fall. The difference is a necessary consequence of the work of various theoretical investigators, however, in particular of Sutton.† In any case we must bear in mind that the assumed values of β may be in error by as much as a factor of 10 perhaps.

The records of drift-snow potential were obtained from a collector 1·8 metres above the rock surface at Rae, but during drift the height of the collector above the snow surface was often much less than this. Further, since the collector protruded from a hut wall its effective height was less than the above, and we shall not be very greatly in error by assuming a height of 1 metre for the collector. Equation (4) must now be considered in relation to (i) low drift, (ii) thick drift.

(i) Low drift—Negative potential at collector level.

From equation (4),

$$\frac{\rho_0}{\alpha^2}(1-e^{-\alpha h})<\frac{\rho_0'}{\beta^2}(1-e^{-\beta h})$$

or

$$\frac{\rho_0}{\alpha}(1-e^{-\alpha h})<\frac{\rho_0'}{\beta}\frac{\alpha}{\beta}(1\ e^{-\beta h}).$$

Putting $\alpha=5\times10^{-2}$, $\beta=5\times10^{-5}$, $h=100$, we have

$$\frac{\rho_0}{\alpha}<5\frac{\rho_0'}{\beta};$$

that is, the total charge on suspended ice particles must be numerically less than about five times the total ionic charge in the air.

(ii) Thick drift—Positive potential at collector level.

From equation (4),

$$\frac{\rho_0}{\alpha}(1-e^{-\alpha h})>\frac{\rho_0'}{\beta}\frac{\alpha}{\beta}(1-e^{-\beta h}).$$

Putting $\alpha=10^{-2}$, $\beta=10^{-5}$, $h=100$, we have

$$\frac{\rho_0}{\alpha}>1\cdot6\frac{\rho_0'}{\beta};$$

that is, the total charge on ice particles must be greater than 1·6 times the air charge.

It is seen that the conditions derived under (i) and (ii) are mutually compatible.

* A. Wigand, *Ann. d. Physik*, 4, 689.

† O. G. Sutton, *Proc. Roy. Soc.*, A, 858, 146, p. 707 (1934).

Further, by changing α and β within the possible limits of these quantities, no appreciable difference is made in the above relations, and we can safely conclude that the total positive charge on ice particles must be greater than the total negative charge on air ions, numerically, but not greater than about ten times the latter.

In any process of charge separation equal quantities of positive and negative electricity are produced, but in the case of drift snow a proportion of the charge on the ice particles is effectively lost, due to the fall-out of particles to the ground. Further, charge separation occurring during momentary contact between ice particles and the surface snow, or as ice particles are torn from the surface (together, probably the main source of charge production), will involve the effective loss of that part of the charge taken up by the surface snow. Losses in both the particle charge and the air charge will occur during contact with the ground by virtue of the turbulent motions of each, and this loss will probably be greater for particle charge whose density near the ground is much greater. Consequently even more charge is likely to be produced on particles in relation to charge in the air than the above numerical relation suggests.

If the above arguments are valid, then the process of charge separation must involve a positive charge on ice particles, a smaller negative charge on the surface snow, and the deficit of negative charge on the air in ionic form. This appears to be the only way in which most of the negative charge produced during the separation process can be effectively lost. The picture may of course be only statistically true when many charge separations are considered. If appreciable charge is produced during collisions between ice particles themselves it would seem necessary for the larger particles to be negatively charged, the smaller positively charged with perhaps a deficit of negative charge taken up by the air.

Unfortunately no profitable appeal can be made to experimental results, which have often been conflicting, concerning the charge separation process. Nakaya and Terada * have recently made experiments on the electrification of dust particles by friction in an air blast, and find in general a greater charge of one sign than of the opposite in the resulting cloud, the excess, however, being generally negative for the dusts they employed (resin, coal dust, lycopodium). They state that excess positive charges may be produced in some cases.

The occasion of negative gradient on 1933 May 16 already referred to is of particular interest in relation to the mathematical theory developed above. On that occasion most of the snow at Fort Rae had disappeared, but much probably remained at more sheltered places some distance away. Since the sky was clear but the wind quite sufficient to produce drift if snow existed, it is reasonable to suppose that the negative space charge observed and the negative gradient were the result of drift snow some distance away. The drift particles would have fallen out of the atmosphere in the intervening stretch of country, but the air would continue to carry its charge over much greater distances. The space charge measured can only be approximate since the measurement was made with the small ion counter. Considering equation (4), the first term inside the square brackets is zero, but a term must be included for the normal fine weather field, since the gradient was only -47 v/m at the time of the ion-counting measurement. We then obtain a value of β equal to 4×10^{-4} per cm. This is not an unreasonable value, for it applies to the end of the period of negative gradient when the air may no longer have retained a normal distribution of charge, probably on account of horizontal diffusion.

No other investigation of drift-snow potentials has seemed to show such a well-defined difference between low drift and thick drift as the Rae results, though Currie † noted negative gradients occasionally at the end of periods of drift. Simpson ‡ found positive gradients in general both with low and high drift, though a few occasions of negative gradients were observed. Such results may be consistent with the conclusions made concerning the process of charge separation, for the

* A. Nakaya and T. Terada, *Phil. Mag.*, 19, 124, pp. 115–123 (1935).

† B. W. Currie, *Terr. Mag.*, 39, 1, p. 30 (1934).

‡ G. C. Simpson, *British Antarctic Expedition, 1910–13*, "Meteorology," Part I, p. 309.

analysis shows that at $h = 100$ cm., and for low drift values of α and β, the potential at the collector will always be positive if

$$\frac{\rho_0}{\alpha} > 5\frac{\rho_0'}{\beta}.$$

This implies that a smaller percentage of the negative charge produced should be taken up by the air than in the drift regime typical of Rae. Such a difference may possibly be due to the state of the snow. At Rae the snow was for the most part quite dry, and on most occasions the snowfall was in the form of small particles of dimensions of about 1 mm.

In this discussion it has been assumed that the snow surface was a sufficiently good conductor to maintain it at zero potential. This assumption was not tested experimentally, but a test was made on the walls of the log hut in which the electrograph was housed. Although the wood was exceptionally dry no deflection was obtained on a Wulf electrometer when connected by a probe to the hut walls, the case being well earthed. Tests were made during heavy drift.

(d) *Potential gradient and auroral activity.*—A number of investigators have sought for a possible correlation between potential gradient and auroral activity. Generally no well-marked relation has been found, and it is certain that no obvious changes occur in the gradient as auroral activity waxes and wanes. Yet certain workers claim to have established some correlation between the phenomena. For example, Sherman * finds that whilst simultaneous pulses of potential gradient and aurora do not occur, the effect of an auroral display is to cause a depression of the gradient following the display. Scholz,† by choosing two occasions when meteorological conditions were very quiet, and when aurora was partly present and partly absent, found that the onset of aurora coincided in each case with an appreciable decrease in the gradient, from 120 to 87 volts/metre in one case and from 79 to 46 volts/metre in the other.

There appears to be good reason why auroral activity should leave potential gradient very little affected at ground level. In the first place, the total amount of charge associated with an auroral display is likely to be relatively small. Since aurora occurs at a large height in the atmosphere, the effect of such charge must be spread necessarily over a wide area.

It seemed worth while, however, to make a detailed investigation of any possible correlation between aurora and potential gradient at the earth's surface. The method adopted was as follows. Hours were taken for which the auroral activity had been assessed on the international scale of character figures 0–4. For these hours the difference was taken between the value of the gradient for the hour of auroral observation and the mean monthly value for the hour in question for quiet days. The results are shown in Table 2, not for each month separately, since the scatter of differences masks any effect present, but for the months September to May collectively.

TABLE 2.—DIFFERENCES BETWEEN POTENTIAL GRADIENT AT HOURS OF AURORAL OBSERVATION AND MEAN MONTHLY VALUE OF POTENTIAL GRADIENT FOR HOURS IN QUESTION.

(Means for September to May 1932–33.)

	Auroral Character Figure.					
	0.	0+.	1.	2.	3.	4.
Mean differences: v/m .	+4·5	+1·6	+3·9	−0·4	−3·9	+2·5
Number of hours used .	16	48	163	224	109	22

* K. L. Sherman, *Trans. Amer. Geophys. Union*, pp. 141–142 (1934).
† J. Scholz, *Beitr. f. Geophys.*, 44, 2, pp. 145–156 (1935).

In this analysis only those hours were used, of course, in which the gradient was undisturbed by such influences as drift snow, precipitation, etc. The first point which calls for mention on examining Table 2 is that for no aurora (character figure 0) a positive departure of 4·5 volts per metre is shown. This is almost certainly due to the fact that auroral figures could not be assessed on nights when the sky was overcast or heavily clouded. Now it has been shown by several workers that the effect of a heavy sheet of low cloud is to depress the gradient slightly. Hence the positive departure shown in column one can be fairly certainly interpreted as the effect of the absence of low cloud.

When the mean differences in gradient are examined in relation to intensity of aurora, there is a rather uncertain suggestion that with increasing intensity of aurora the gradient becomes progressively depressed. The departures for auroral character figures 1 and 4 break the apparent progression. The relatively small number of hours used for auroral character 4 may account for the break there, but this does not apply to auroral character 1.

A re-examination of the figures in terms of frequency of positive and negative departures from the mean gradient has been made, and the results are given in Table 3.

TABLE 3.—FREQUENCY OF POSITIVE AND NEGATIVE DEPARTURES FROM THE MEAN GRADIENT WITH RESPECT TO AURORAL ACTIVITY.

	Auroral Character Figure.					
	0.	0+.	1.	2.	3.	4.
Number of +ve departures, N_+ .	10	29	89	105	36	12
Number of −ve ,, , N_- .	6	19	72	116	68	10
Number of zero ,, .	0	0	2	4	5	0
Ratio, N_+/N_-	1·7	1·5	1·2	0·9	0·5	1·2

This shows a progression similar to that in Table 2 but more consistent, auroral character 4 being the only one to break the run.

I am indebted to Dr F. J. W. Whipple for the suggestion that the figures of Table 3 are admirably suited for a test of significance known in statistical theory as the χ^2 test.* Granted sufficient observations, and Table 3 is quite satisfactory in this respect, the χ^2 test shows whether the above figures for N_+ and N_- are likely as the result of chance. It is unnecessary to give details of the test here, particulars of which may be found from the reference quoted, but its application shows that such a distribution of values as is given in Table 3 does possess significance.

There is justification, therefore, from Tables 2 and 3 for assuming that auroral activity slightly diminishes the gradient near the earth's surface, the depression increasing with increasing auroral intensity, but not exceeding in general a few volts per metre (Table 2 shows a maximum mean departure of $-(4{\cdot}5+3{\cdot}9)=-8{\cdot}4$ v/m for auroral character 3).

A more direct test than the above, by comparing gradient values on nights when aurora did or did not occur, could not be made, since aurora was observed on all nights when sky conditions made observation possible.

The slight depression of the gradient near the earth's surface by auroral activity is presumably to be interpreted as the effect of the penetration of the upper atmosphere at auroral levels by negatively charged particles or by particles which carry a net negative charge.

* See, for example, R. A. Fisher, *Statistical Methods for Research Workers*, chap. iv, London (1925).

II. *Small ion content, conductivity, air-earth current, condensation nuclei, and rate of production of ions.* (a) *General.*—The observed values of positive and negative small ion content, n_+ and n_-, are given in Table 285, Vol. II, together with mean values, values of the ratio n_+/n_- and of the ratio of values obtained at 16h 30m and 22h 30m G.M.T. Table 286, Vol. II, gives the observed values of positive polar conductivity, λ_+, and air-earth current, i, mean values and values of the ratios of the quantities at 16h 30m and 22h 30m G.M.T. Table 287, Vol. II, gives the more limited series of observations on the number of condensation nuclei, Z.

Both small ion content and conductivity are relatively high at Fort Rae, and this is due first to the high rate of production of ions near the ground, and second to the low concentration of condensation nuclei. The small ion content varied in general between 1000 and 2000 per c.c. of either sign, and the positive polar conductivity between 20 and 40×10^{-5} e.s.u., values rather more than twice those normally found at land stations. The condensation nuclei normally numbered less than 1000 per c.c. unless the effects of local fires were encountered. Measurements were made on a number of occasions of the rate of production of ions, q, near the ground, and the results are given in Table 4. These values naturally show a fairly large variation, but they are all considerably above the average value of about 10 J ion pairs/c.c./sec. for land stations. Also it has been stated (2, V) that the values measured are likely to be an underestimate of the actual rate of production of ions.

TABLE 4.

Date.	Time, G.M.T.	q.
1932 Aug. 11	14h 05–25m	15·3 J
Oct. 21	23h 40–57m	18·1
1933 Feb. 7	23h 30–45m	20·3
Mar. 7	21h 45m–22h 00m	15·7
May 2	0–24h	14·0
May 4	0–24h	13·6
May 11	0–24h	14·7
Aug. 26	21h 06–18m	18·1
Aug. 26	21h 36–48m	18·5

The relation between the above quantities is considered more fully later (3, III).

It has already been stated that many observations of ion content, etc., were affected by smoke from fires in the settlement. A fire might be started at some hut to windward during an observation, or a slight shift in wind direction would bring smoke over the observation site which had been previously clear of pollution. On such occasions both small ion content and conductivity would drop to a greater or less extent, and when observations of condensation nuclei were being made these would show a large increase. Those results most obviously affected by local pollution and noticed at the time have been deleted, but it is fairly certain that much of the irregularity which remains in the observations is due to this cause though the effects were not sufficiently obvious at the time to be questioned. Unfortunately, the winter was the most troublesome period in respect of smoke, when observations were fewest and when condensation nuclei observations were rarely available, for the latter formed the best indirect evidence for the presence of smoke. In the analysis which follows, observations which are likely to have been influenced by pollution have been omitted; the criterion adopted was to exclude observations when the wind direction made the observation site particularly prone to smoke.

(b) *Effect of wind velocity* (*atmospheric turbulence*).—The observations of ion content, conductivity, air-earth current, and nuclear content have been grouped according to the wind velocity at the time of observation, and the results are shown graphically in fig. 3 in the five upper curves. Each element except nuclear content shows a marked dependence on wind velocity, an increase in wind corresponding to a decrease in the value of each element, but the decrease becomes less for proportionately increasing wind velocity. This relationship is the reverse of that found between potential gradient and wind velocity, also shown in fig. 3, and previously discussed in 3, I (*b*). The ratio of values at wind velocities of 0·25 and 8·0 m/s are as follows:—

n_+	1·47
n_-	1·41
λ_+	1·46
i	1·37

The ratios for n_+ and λ_+ agree almost exactly, as would be expected, for λ_+ is directly proportional to n_+, assuming no appreciable contribution to λ_+ from intermediate or large ion content and a constant mobility of small ions. Also it is to be expected that the ratio for i would be less, since i is determined both by conductivity and field, which have opposite variations.

The relation between the electrical elements and wind velocity is an important one, for it appears to give consistency to all the electrical observations at Fort Rae. The explanation of the relationship lies in the diffusing power of a turbulent wind. Any natural wind is generally turbulent, and the eddying velocities in general increase at least proportionately with increase in wind velocity (constant gustiness). Now the rate of production of ions is a maximum near the ground * if only the first few kilometres of the atmosphere are considered. Hence in low winds, when the vertical transport by diffusion of ions and ion-producing agencies is a minimum, ion content and conductivity will be a maximum near the ground, but as the wind increases vertical transport will increase with it, and ion content and conductivity will be correspondingly reduced near the ground. No complication arises in this argument due to change in nuclear content and large ion number, for fig. 3 shows nuclear content to be practically independent of wind velocity; *i.e.* the degree of vertical mixing does not appreciably affect the number of nuclei near the ground at Fort Rae. This is to be expected when the sources of these nuclei are almost certainly very remote from Rae, the nuclei having become evenly diffused through the lower atmosphere a great distance before reaching Rae.

(c) *Relative values of elements at 16h 30m and 22h 30m G.M.T.*—In general the 16h 30m values of ion content, conductivity, and air-earth current are higher than the 22h 30m values. The mean ratios for all months are given in Table 5, and it is seen that the ratios for n_+, n_-, and λ_+ are almost consistently greater than unity with relatively little scatter in the monthly means, showing that there is a well-marked variation in these elements between 16h 30m and 22h 30m. The ratio for i is about the same as that for the other elements, but shows a much wider range in values from month to month, suggesting that on the whole the current tends to follow conductivity in its variations.

TABLE 5.—RATIO OF VALUES OBSERVED AT 16h 30m AND 22h 30m G.M.T.

Element.	Mean Ratio.	Extremes of Monthly Mean Ratios.
n_+	1·09	0·96–1·29
n_-	1·10	0·98–1·22
λ_+	1·09	0·91–1·31
i	1·11	0·78–1·52

Further aspects of the variation shown here will be discussed in 3, II (*e*) under diurnal variation of the elements.

* V. F. Hess, *Beitr. Geophys. Erg. d. kosm. Phys.*, II, p. 145 (1933).

(d) *Annual variation.*—From the figures given in Tables 285 and 286, Vol. II, it is difficult to infer any precise variation of the elements during the year. When those observations have been deleted, however, which are likely to have been influenced by pollution from local fires, variations as shown in fig. 4 are obtained, where the points plotted refer to the means for both 16h 30m and 22h 30m observations (no points have been plotted for December, for all the observations were suspect on account of smoke). There appears to be a fairly well-defined annual variation of ion content and conductivity, with a maximum in winter months and a minimum

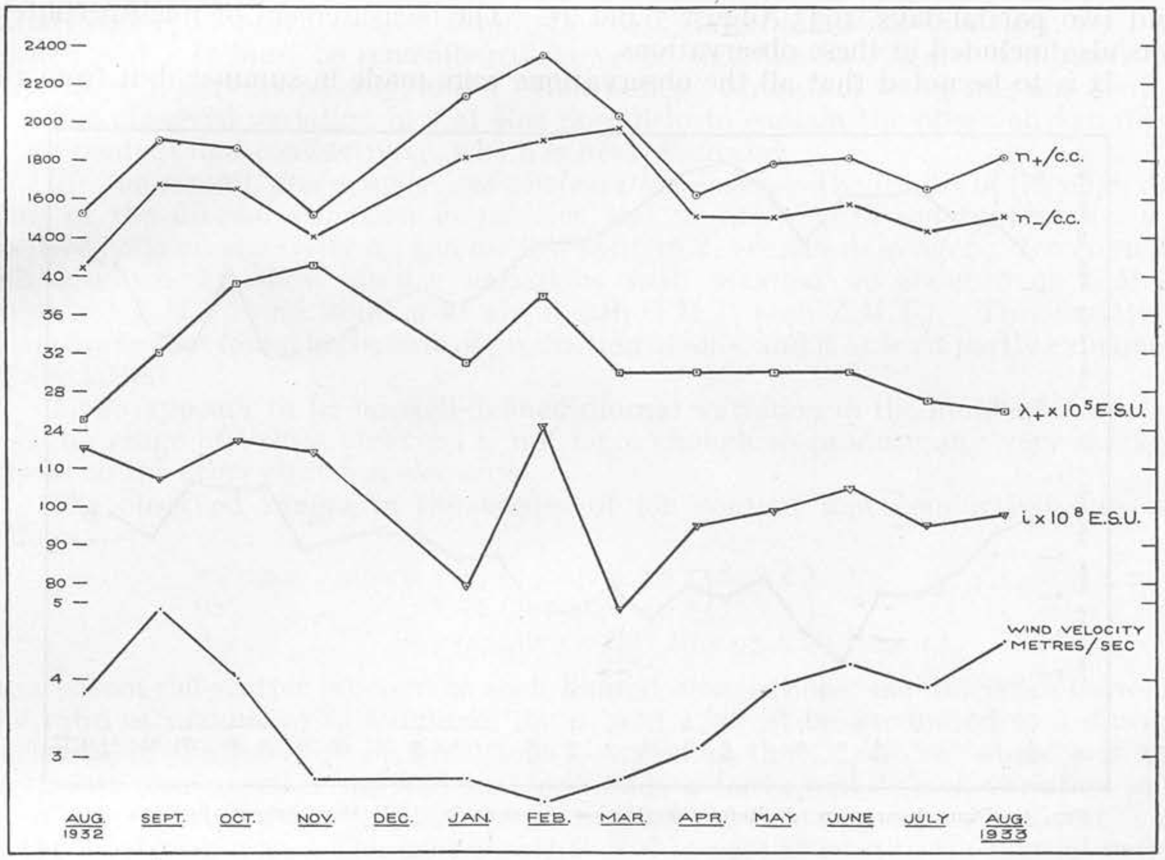

FIG. 4.—Annual variation of atmospheric electrical elements and wind velocity.

during the summer. The evidence for variation in the air-earth current is not so certain. To some extent the current curve has the same form as the conductivity curve, but it possesses both maximum and minimum in or near winter.

Now, in fig. 4 the annual variation of wind velocity has also been plotted for those days on which electrical observations have been used, and, as would be expected from the relation shown in fig. 3, the curves of ion content and conductivity are approximate mirror images of the wind-velocity curve. The August 1932 values for ion content and conductivity derived from a reliable number of observations are lower than are to be expected from this relationship, due almost certainly to the influence of an increase in nuclei arising from bush fires to windward of the station, which occurred during a large part of the month. From the curve connecting air-earth current and wind velocity given in fig. 3, it appears probable that if the scatter due to various causes could be eliminated from the current curve of fig. 4, the latter would also show a variation with maximum in winter and minimum in summer, as for conductivity, *i.e.* the reverse of the potential gradient variation.

(e) *Diurnal variation.*—It has been stated that some attempt was made to determine the form of the diurnal variation of the electrical elements other than potential gradient by means of the eye-reading instruments. All that could be done was to make observations of the usual kind at each hour of the day on a few days when the weather conditions appeared likely to remain steady and fine. Three sets of 24-hourly observations were quite readily obtained of the rate of production of ions in a closed vessel on 1933 May 2, 4, and 11, and as the resulting curves showed a consistent type of variation, these observations were made to suffice. Many attempts were made to obtain satisfactory series of observations of ion content, conductivity, and air-earth current, but weather changes and experimental troubles caused the suspension of a number of them. Finally four sets of hourly observations were obtained from the work of three complete days, 1933 June 22 and 29, July 28, and two partial days, 1933 August 5 and 25. The measurement of nuclear content was also included in these observations.

It is to be noted that all the observations were made in summer, but from the

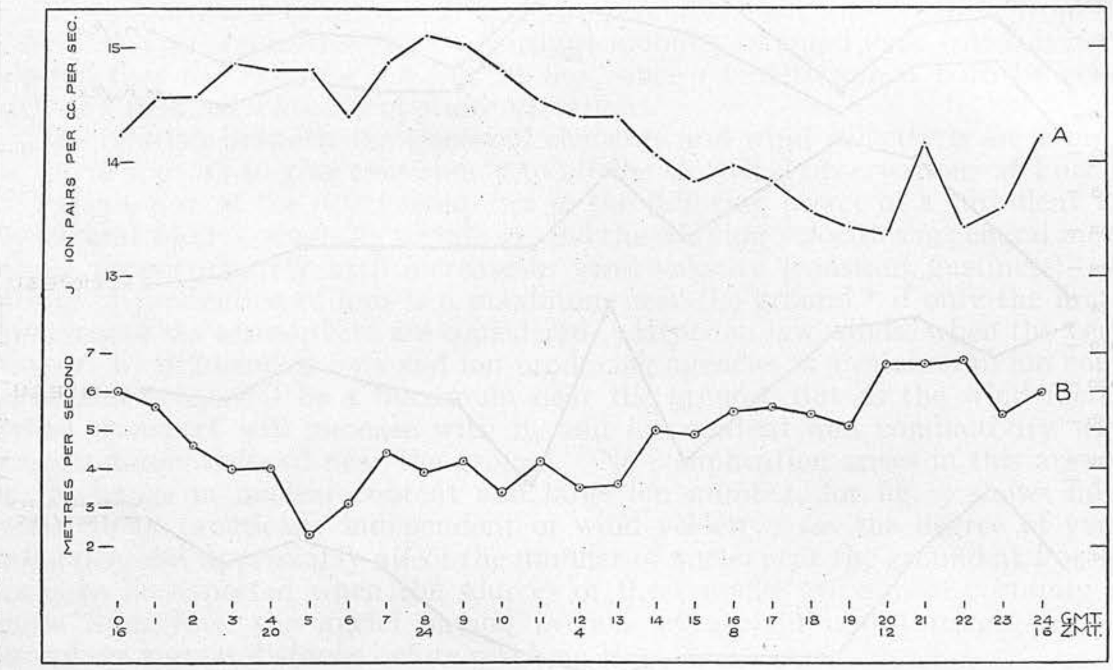

FIG. 5.—Diurnal variation: A. Rate of production of ions (3 days); B. Wind velocity for same days.

general behaviour of the electrical elements it is thought that the variations found are likely to be true in kind for all seasons.

(i) *Rate of production of ions*.—The mean values for the rate of production of ions, q, in a closed vessel on three days are shown in fig. 5, curve A, together with the diurnal variation in wind velocity for the same days, curve B.

There is a well-defined variation in q with a maximum of 15·1 J (ion pairs/c.c./sec.) at about 8h G.M.T. (0h Z.M.T.), and a minimum of 13·4 J at about 20h G.M.T. (12h Z.M.T.). The ratio of maximum to minimum is 1·13 and the range 1·7 J, but for reasons stated in 2, V, the latter figure is likely to be an underestimate of the actual change in q for the free air.

Now the rate of production of ions is known to be affected by a number of conditions, such as the state of the soil and the upward or downward trend of the barometer. Such effects are not likely, however, to have a well-marked diurnal change at a station such as Fort Rae. (The observations having been made over solid granite, the state of ground is presumably of little influence.) But if the arguments advanced in 3, II (b) are correct, there will be an effect due to vertical transport of ionising agencies in the atmosphere, and this will lead to a diurnal change in q, the inverse of the diurnal change in wind velocity. This relation appears to be supported by the two curves of fig. 5. It is also to be noted that the curve for q is roughly opposite in phase to the diurnal variation of potential gradient (maximum at 18h and minimum at 4h G.M.T.), and it may be that precipitation of radioactive matter by the earth's field helps to contribute something to the variation in q, low fields giving minimum precipitation and high values of q, and high fields maximum precipitation and low values of q.

Hogg * has inferred from his observations at Canberra, and from observations by Wait and Nolan at Washington and Glencree respectively, that there is a world-wide diurnal wave in the rate of production of ions progressing according to universal time, with a maximum at about 17h and a minimum at about 2–4h G.M.T. There is no evidence for this variation in the Rae figures, which show very nearly an opposite variation, but of much smaller amplitude than that obtained at Canberra, 1·7 J as against 20 J. It must be remembered, however, that the Rae figures are based on three days' observations only, and a "thin-walled" ionisation vessel was not used.

The observed variation in q at Rae does help to explain the observed variation in ion content and conductivity, which is next discussed.

(ii) *Ion content, conductivity, and condensation nuclei.*—The results of the observations of the diurnal variation in positive and negative small ion content n_+, n_-, positive polar conductivity λ_+, and nuclear content Z, are shown in fig. 6. Ion content and conductivity show similar variations with maxima at about 7–9h G.M.T. (midnight Z.M.T.) and minima at about 22h G.M.T. (14h Z.M.T.). This variation is similar to that found in the rate of production of ions, and is at least partly explained by the latter.

There appears to be no well-defined diurnal variation in the number of nuclei, and the range of values observed is not large enough to produce any very marked effects on the other electrical elements.

The observed ranges in the values of ion content and conductivity are as follows:—

n_+ max. : min.	$= 1{\cdot}49$	(2360/c.c. to 1580/c.c.).
n_- ,,	$= 1{\cdot}51$	(2070/c.c. to 1370/c.c.).
λ_+ ,,	$= 1{\cdot}90$	($46{\cdot}7 \times 10^{-5}$ to $24{\cdot}5 \times 10^{-5}$ e.s.u.).

Apart from the scatter inherent in such limited observations, the difference between the ratio of maximum to minimum for n_+ and λ_+ must be attributed to a diurnal variation in the mobility of small ions. Assuming that $\lambda_+ = n_+ek$, where e is the electronic charge and k the mobility, one finds a fairly well-defined variation in k from 1·5 cm. : sec./volt : cm. at about midnight local time to 1·0 cm. : sec./volt : cm. in the local afternoon. This may be attributed in part at least to the diurnal variation of vapour-pressure, with a minimum during the local night hours and a maximum during the local afternoon. Part of the variation may, however, reflect a variation in intermediate ion content of range greater than that shown for small ion content. No observations of intermediate ion content were made however.

Apart from the effect of rate of production of ions on ion content and conductivity, it seems probable that in an atmosphere where condensation nuclei are approximately evenly diffused, and where small ion density therefore tends to be a maximum near the ground, there will be a progressive decrease in ion content and conductivity with increase of vertical mixing by turbulence, *i.e.* with increase in wind velocity. The curve for wind velocity variation on the days of the electrical observations is given in fig. 6 and is consistent with this argument. The absence of any well-defined diurnal variation in nuclear content is also consistent with the assumption of an approximately even diffusion of nuclei in the lower atmospheric layers on account of their remote point of origin.

The observed variation in conductivity must react on the variation in field strength, but since the world-wide variation in field is already rather similar to the variation which would be imposed by conductivity changes near the ground at Rae, the two effects are difficult to separate.

(iii) *Air-earth current.*—The diurnal variation of the air-earth current is also shown

* W. R. Hogg, *Beitr. Geophys.*, **43**, 4, p. 359 (1934).

in fig. 6 together with the field, both elements being measured directly by means of the modified Wilson apparatus and therefore given in relative values.

The variation in current is not so clearly defined as in the other elements, but there is a general tendency for the current to follow variations in field strength rather

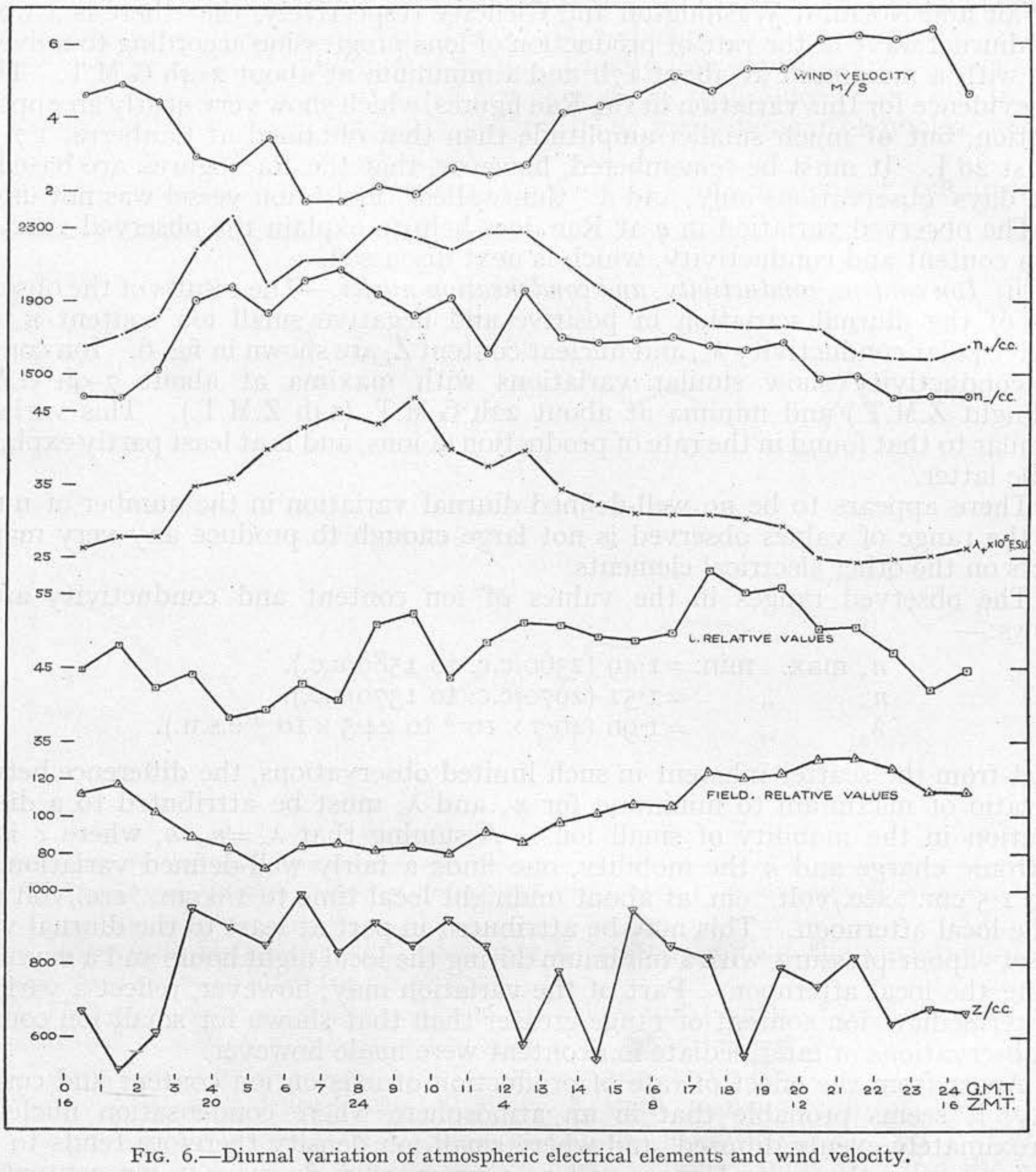

FIG. 6.—Diurnal variation of atmospheric electrical elements and wind velocity.

than in conductivity. The current reaches a maximum at about 18h G.M.T. (10h Z.M.T) and a minimum at 4h G.M.T. (20h Z.M.T.). The ratios of maximum to minimum for current and field are:

i 1·52 or $\pm$ 26 per cent. about the mean.
F 1·83 or $\pm$ 41 ,, ,, ,,

As is to be expected, the range of i is less than that of F, for the current is controlled by both conductivity and field, and the variations in the two latter elements are opposed.

Scrase * has shown that for Kew the air-earth current follows closely the changes in conductivity as opposed to field in winter, and the changes in field as opposed to

* F. J. Scrase, *London Meteorological Office, Geophys. Mem.*, No. 58 (1933).

conductivity in summer. This behaviour is ascribed to the overwhelming effects of atmospheric pollution in winter, which are of much smaller magnitude in summer and so allow a more fundamental relationship to show itself. This is supported by the observations taken on board the S.S. *Carnegie*, which have been discussed by Mauchly,* who finds a very close relationship between the variation of air-earth current and electric field over the ocean. The observations at Rae are intermediate between the above, for whereas pollution effects are absent from both the Rae and *Carnegie* results, at Rae the current is partially controlled by conductivity variations as at Kew, but to a smaller extent. At sea, conductivity variations are negligible, for ionisation is approximately constant there. The Rae results would seem to be most typical of the behaviour of current variations over land, for only relatively small areas of land are greatly affected by pollution. In which case it would seem that over the sea, and to a less but still preponderating extent over the land, the air-earth current is controlled by, and reflects variations in, the potential of the upper conducting layer of the atmosphere, at least for the shorter period, *e.g.* diurnal, changes. The long period annual variations in current, however, over land seem to follow conductivity changes rather than changes in the field, for it has been suggested that the annual variation in current at Rae behaves thus, though the observations are not sufficiently numerous to give certainty, and Scrase at Kew has found an annual variation in current similar to, though of much less amplitude than, the variation in conductivity.

III. *Equilibrium of atmospheric ionisation.*—Using the following notation:—

q = rate of production of ion pairs/c.c./sec.,
n = mean of positive and negative small ion densities,
α = recombination coefficient for small ions of opposite sign,
N_0 = number of uncharged nuclei/c.c.,
N = mean of positive and negative large ion densities,
η_1 = combination coefficient for small ions and uncharged nuclei,
η_2 = combination coefficient for small ions and large ions of opposite sign,
Z = total number of nuclei, charged and uncharged, so that
$Z = N_0 + 2N$,

we obtain the following approximate equations for the equilibrium of atmospheric ionisation:—

$$q = \alpha n^2 + \eta_1 N_0 n + \eta_2 N n,$$

$$\eta_1 N_0 n = \eta_2 N n,$$

so that

$$q = \alpha n^2 + 2\eta_2 N n. \qquad (1)$$

These equations are approximate, for they do not differentiate between the equilibrium of positive ions and negative ions, large or small, and the coefficients employed may be different according as positive small ions or negative small ions are being considered. However, for the present purpose they will be taken as sufficiently adequate.

Unfortunately, no measurements were made at Rae of the combination coefficients for small ions and charged or uncharged nuclei, neither were the numbers of charged and uncharged nuclei separately determined. Consequently no complete application of the above equations can be made, but it seemed worth while to make calculations of the rate of production of ions, using equation (1) and making certain assumptions.

The value of α is known from laboratory experiments to be $1{\cdot}6 \times 10^{-6}$ c.c./sec., but experimental determinations of η_2 show a large range of values. We shall adopt here the value $6{\cdot}8 \times 10^{-6}$ c.c./sec. found by Hess † in experiments on Heligoland, but it appears that η_2 is not necessarily a constant, and will vary over an appreciable range at any one place according to the type and size of nuclei present.

The ratio N_0/N ($=p$, say) has been determined by a number of workers and a

* S. P. Mauchly, Carnegie Institute, Washington, Res. Dept., *Terr. Mag.*, **5** (1926).

† V. F. Hess, *Beitr. Geophys.*, **22**, p. 256 (1929).

fairly wide range of values obtained. A value of about 2·2 has been most commonly found, but both Israel * and Schachl † find that the ratio decreases considerably for small nuclear densities of about 1000/c.c. or less. In the calculations which follow, p has been alternatively set at 1·0 and 2·2.

Since $Z = N_0 + 2N$ and $N_0/N = p$, we have

$$N = \frac{Z}{2+p}.$$

Equation (1) can therefore be written:

$$q = \alpha n^2 + \frac{2\eta_2 n Z}{2+p} \quad . \quad . \quad . \quad . \qquad (2)$$

Equation (2) has been used to calculate q from the mean observations of four months in 1933, for which reliable mean values are available for ion content and nuclear content, and from the mean observations made hourly on three days in 1933. Table 6 gives the results of these calculations, and it is seen that the values

TABLE 6.—CALCULATED VALUES OF q.

Date.	n.	αn^2.	Z.	$2\eta_2 nZ/(2+p)$.		q.	
				$p=1·0$.	$p=2·2$.	$p=1·0$.	$p=2·2$.
May 16h 30m G.M.T.	1700	4·6	815	6·3	4·5	10·9	9·1
22h 30m ,,	1500	3·6	710	4·8	3·5	8·4	7·1
June 16h 30m ,,	1680	4·5	670	5·1	3·7	9·6	8·2
22h 30m ,,	1690	4·6	555	4·2	3·0	8·8	7·6
July 16h 30m ,,	1570	3·9	1270	9·0	6·5	12·9	10·4
22h 30m ,,	1490	3·6	1060	7·1	5·1	10·7	8·7
Aug. 16h 30m ,,	1850	5·5	835	7·0	5·0	12·5	10·5
22h 30m ,,	1470	3·5	890	5·9	4·2	9·4	7·7
June 29, 0–24h	1730	4·8	580	4·5	3·5	9·3	8·3
July 28, 0–24h	1810	5·2	1230	10·1	7·2	15·3	12·4
Aug. 5 and 25, 0–24h	1850	5·5	520	4·4	3·1	9·9	8·6

obtained for q are nearly all appreciably lower than the values observed in the ionisation vessel, viz. 13·6 to 20·3 J, themselves liable to be underestimates. This is the case both for $p=1·0$ and 2·2, but on the two occasions on which Z appreciably exceeded 1000/c.c., $p=1$ gives values of q which are about the same as those obtained with the ionisation vessel.

One concludes, therefore, that at Rae either the ratio N_0/N must be generally less than unity, *i.e.* less than one-third of the nuclei are uncharged, or the combination coefficient between small ions and large ions must be considerably greater than the value assumed, viz. $6·8 \times 10^{-6}$ c.c./sec.

A further point arises from Table 6. The 16h 30m G.M.T. observations lead to consistently higher values for q than the 22h 30m G.M.T. observations. This is consistent with the direct observations on the diurnal variation of rate of production of ions, but the calculated difference is greater than that observed (*vide* fig. 5). It has already been suggested that the experimental curve does not show the full variation in q.

In conclusion, the writer wishes to express his gratitude to the members of the expedition (Messrs J. M. Stagg, W. R. Morgans, and W. A. Grinsted) who assisted in

* H. Israel, *Zeit. Geophys.*, 7, p. 127 (1931).

† P. F. Schachl, *Beitr. Geophys.*, 38, p. 202 (1933).

taking observations and attending to apparatus when the writer was absent from the main station or otherwise occupied. In particular, thanks are due to Mr J. M. Stagg and Mr W. A. Grinsted for assisting in the 24-hourly series of observations, which required much application and care.

4. SUMMARY

(1) The diurnal variation of potential gradient on "quiet" days is found to follow the universal time wave, with minimum at about 4h and maximum at about 20h G.M.T.

(2) Potential gradient on "quiet" days is at a maximum in summer and a minimum in winter. This is tentatively explained as an effect of atmospheric turbulence, since the gradient shows a marked increase with increase in wind velocity, and the winds in winter on "quiet" days are less than those in summer and of smaller turbulence.

(3) The disturbances in the gradient due to drift snow are discussed fully.

(4) Some evidence is produced to show that auroral activity depresses the gradient, and this is interpreted as the result of negatively charged particles penetrating the upper atmosphere.

(5) The small ion content, positive polar conductivity, and air-earth current are found to decrease with increase in wind velocity, and this is probably due to effects of atmospheric turbulence, a greater upward transfer of ions occurring in the air near the ground in high winds than in low winds.

(6) Ion content and conductivity are at a maximum in winter and a minimum in summer, whilst the diurnal variations show a maximum at about local midnight and a minimum in the local afternoon. These variations are the result of annual and diurnal wind variation as suggested by (5).

(7) The air-earth current shows rather irregular variations, but it is suggested that diurnally it tends to follow field variations and annually to follow conductivity variations.

(8) The rate of production of ions in the air near the ground is found to have a diurnal variation similar to that of ion content and conductivity, and for similar reasons.

(9) There appears to be no significant variation in the number of condensation nuclei.

(10) The equilibrium of atmospheric ionisation is discussed, and it is inferred that probably less than one-third of the condensation nuclei are uncharged.

APPENDIX I

LIST OF FIRMS WHICH CONTRIBUTED IN KIND TO THE EQUIPMENT OF THE BRITISH POLAR YEAR EXPEDITION

Food-stuffs

Aplin & Barrett and the Western Counties Creameries Ltd., London.	Cheese, Butter.
Alfred Bird & Sons Ltd., Birmingham	Custard Powder, Blanc Mange Powder, Baking Powder, Jelly.
Branson & Co. Ltd., London	Coffee.
Brown & Polson Ltd., London	Flour, Cornflour, Custard Powder.
Bryant & May Ltd., London	Matches.
James Buchanan & Co. Ltd., London	Whisky.
Cerebos Ltd., London	Table Salt, Gravy Salt, Pepper.
J. & J. Colman Ltd., Norwich	Flour, Mustard.
Frank Cooper Ltd., Oxford	Marmalade, Mint Jelly, Horse-radish Cream, Chutney.
Crosbie's Pure Food Co. Ltd. (T. G. Tickler Ltd.), Southall	Jam.
Crosse & Blackwell Ltd., London	Tinned Vegetables.
J. Dewar & Sons Ltd., London	Whisky.
J. Farrow & Co. Ltd., Peterborough	Tinned Peas, Tinned Fruits, Packet Peas.
Grape Nuts Co. Ltd., London	Grape Nuts.
Samuel Hanson & Son, London	Dry Goods, Fruit, Tinned Meat.
H. J. Heinz Co. Ltd., London	Tinned Vegetables, etc.
Hugon & Co. Ltd., Manchester	Suet, Lard.
Huntley & Palmers Ltd., Reading	Biscuits and Cakes.
F. King & Co., London	Preserved Potatoes.
Lambert & Butler, London	Cigars.
Nestlé and Anglo-Swiss Condensed Milk Co., London	Condensed Milk.
Oxo Ltd., London	Oxo, Oxade Cocoa.
Plasmon Ltd., London	Plasmon Powder.
J. Player & Sons, Nottingham	Tobacco, Cigarettes.
Quaker Oats Ltd., London	Quaker Oats, Oatmeal.
Redgate & Co. Ltd., London	Ham, Bacon, Sausages.
J. Robertson & Sons Ltd., London	Marmalade, Jam.
L. Rose & Co. Ltd., London	Lime Juice.
Rowntree & Co. Ltd., York	Cocoa, Chocolate.
Ryvita & Co. Ltd., London	Ryvita Crispbread.
Spratt's Patent Ltd., London	Dog Biscuits.
W. Symington & Co. Ltd., Market Harborough	Soups.
Tate & Lyle Ltd., London	Sugar.
Unilever Ltd. (Van den Berghs Ltd.), London	Margarine, Soap.
United Yeast Co. Ltd., London	Powdered Milk.
A. Wander Ltd., London	Ovaltine, Ovaltine Chocolate.
Angus Watson & Co. Ltd., Newcastle-upon-Tyne	Tinned Salmon, Tinned Sardines.
W. D. & H. O. Wills, Bristol	Tobacco, Cigarettes.
Wisbech Produce Canners Ltd., Wisbech	Tinned Fruit and Vegetables.

Equipment and Clothing

Aladdin Industries Ltd., Greenford, Middlesex	Lamps.
Bapty & Co., London	Firearms.
Ernest Benn Ltd., London	Books.
The British Aluminium Co. Ltd., London	25 miles Aluminium Cable.

Burberry's Ltd., London	Polar Suits.
The Chloride Electrical Storage Co. Ltd., London	32-volt Battery.
Columbia Gramophone Co. Ltd., London	Gramophone and Records.
Delco Lighting Co. Ltd., Toronto, Ontario	Charging Plant.
Down Bros. Ltd., London	Surgical Instruments.
Ensign Ltd., London	Cine-camera.*
The Ever Ready Co. (Great Britain) Ltd., London	Battery and Hand-lamp Equipment.
Ferranti Ltd., Hollinwood, Lancashire	Multi-range Test Set.
The General Electric Co. Ltd., London	Wireless Set.
W. T. Henley's Telegraph Works Co. Ltd., London	Cable Insulation.
Hudson's Bay Co. Ltd., Edmonton	Miscellaneous Stores.*
Imperial Chemical Industries Ltd., London	Chemicals.
The Jaeger Co. Ltd., London	Woollen Clothing.*
Johnson & Johnson, Slough, Bucks	Surgical Dressings.
E. Leitz (London), London	Leica Camera.
L. McMichael Ltd., Slough, Bucks	Short Wave Wireless Receiver.†
H. Millward Ltd., London	Fishing Tackle.
The Ormond Engineering Co., London	Loud Speaker.
The Remington Typewriter Co. Ltd., London	Portable Typewriter.*
Siemens Bros. & Co. Ltd., London	Microphones.
Somervell Bros. Ltd., Kendal	Boots.
The Weston Electrical Instrument Co. Ltd., London	Thermo-ammeters.†
Wolsey Ltd., Leicester	Woollen Clothing.*

Transport

Canadian National Railways	Reduced fares and transport rates.
Cunard Steamship Co. Ltd.	,, ,, ,,
Hudson's Bay Co. Ltd.	,, ,, ,,
Northern Alberta Railway Co. Ltd.	,, ,, ,,

* Supplied at reduced prices. † Loan.

APPENDIX II

LOANS

Air Ministry	Main Instrumental Equipment.
Admiralty	Set of Variometers, Recording Apparatus, Earth Inductor, Ammeter, Chronometers, Chronometer Watches, Telescope, Binoculars.
War Office	Fullerphones.
General Post Office	Telephones and Telephone Equipment.
International Union of Geodesy and Geophysics	Auroral Camera, Spectroscopes.
Royal Geographical Society	Micrometer Theodolite, Plane Table.
Professor C. T. R. Wilson, F.R.S., Cambridge	Electrometer.

APPENDIX III

Adopted Base Line Values: D.

36° + Tabulated Values.

Date.	1932.					1933.							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
	′	′	′	′	′	′	′	′	′	′	′	′	′
1	47·3	45·4	44·4	44·7	46·0	48·2	49·5	49·7	48·2	44·9	40·6	38·6	38·9
2	47·2	45·3	44·4	44·7	46·1	48·3	49·6	49·7	48·1	44·8	40·4	38·6	38·9
3	47·2	45·3	44·4	44·7	46·1	48·3	49·6	49·7	48·0	44·6	40·3	38·6	38·8
4	47·1	45·2	44·4	44·8	46·2	48·4	49·6	49·7	47·9	44·5	40·2	38·7	38·8
5	47·0	45·2	44·3	44·8	46·3	48·4	49·6	49·7	47·9	44·3	40·1	38·7	38·8
6	47·0	45·1	44·3	44·9	46·4	48·5	49·6	49·6	47·8	44·2	39·9	38·7	38·8
7	46·9	45·1	44·3	44·9	46·5	48·6	49·6	49·6	47·7	44·0	39·8	38·7	38·7
8	46·8	45·0	44·3	45·0	46·6	48·6	49·7	49·5	47·6	43·9	39·7	38·7	38·7
9	46·8	45·0	44·3	45·0	46·7	48·6	49·7	49·5	47·5	43·7	39·6	38·8	38·6
10	46·7	45·0	44·3	45·0	46·7	48·7	49·7	49·4	47·4	43·6	39·6	38·8	38·6
11	46·6	44·9	44·3	45·1	46·8	48·7	49·7	49·4	47·3	43·5	39·5	38·8	38·6
12	46·6	44·9	44·3	45·1	46·9	48·8	49·7	49·4	47·2	43·3	39·4	38·8	38·5
13	46·5	44·9	44·3	45·2	46·9	48·8	49·7	49·4	47·2	43·2	39·3	38·8	38·4
14	46·4	44·8	44·3	45·2	47·0	48·9	49·7	49·3	47·1	43·0	39·2	38·8	38·4
15	46·4	44·8	44·4	45·3	47·0	48·9	49·7	49·2	47·0	43·8	39·1	38·9	38·4
16	46·3	44·8	44·4	45·3	47·1	49·0	49·7	49·2	46·9	42·7	39·0	38·9	38·3
17	46·3	44·7	44·4	45·4	47·2	49·0	49·7	49·1	46·8	42·6	39·0	38·9	38·2
18	46·2	44·7	44·4	45·4	47·3	49·0	49·7	49·1	46·6	42·4	39·0	38·9	38·1
19	46·2	44·7	44·4	45·5	47·3	49·1	49·7	49·0	46·5	42·3	38·9	39·0	38·1
20	46·1	44·6	44·4	45·5	47·4	49·1	49·7	48·9	46·4	42·1	38·9	39·0	38·0
21	46·0	44·6	44·4	45·5	47·5	49·2	49·7	48·9	46·2	42·0	38·8	39·0	37·9
22	46·0	44·6	44·4	45·6	47·6	49·2	49·7	48·8	46·1	41·9	38·8	39·0	37·9
23	45·9	44·5	44·4	45·6	47·6	49·2	49·7	48·8	46·0	41·7	38·8	39·0	37·8
24	45·9	44·5	44·5	45·7	47·7	49·3	49·7	48·7	45·9	41·6	38·7	39·0	37·7
25	45·8	44·5	44·5	45·7	47·8	49·3	49·7	48·6	45·8	41·4	38·7	39·0	37·6
26	45·7	44·4	44·5	45·8	47·8	49·4	49·7	48·6	45·6	41·3	38·6	39·0	37·6
27	45·7	44·4	44·5	45·8	47·9	49·4	49·7	48·5	45·5	41·2	38·6	39·0	37·5
28	45·6	44·4	44·6	45·9	48·0	49·4	49·7	48·4	45·3	41·0	38·6	39·0	37·4
29	45·6	44·4	44·6	46·0	48·0	49·4	..	48·4	45·2	40·9	38·6	39·0	37·3
30	45·5	44·4	44·6	46·0	48·1	49·5	..	48·3	45·0	40·8	38·6	39·0	37·2
31	45·4	..	44·7	..	48·2	49·5	..	48·2	..	40·7	..	38·9	37·1

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